COLUMNS AND WALLS:
THE INTERPLAY BETWEEN STRUCTURE AND SPACE

by
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Abstract

This thesis studies the fundamental structural systems of columns and walls as formers of space. The research program is built on the interplay between the structural form, constituted by structural principles and schemes, and the spatial form composed of spatial geometry and configuration. Structural principles refer to the load-transfer mechanism; the structural scheme, to the dimensions and the spatial positions of columns and walls. Spatial geometry relates to the formal shape and configuration to the connection and positional patterns of spaces. A range of spatial forms is considered in terms of the degree of spatial confinement ranging from a virtual spatial form, such as a free-standing column or wall to a physically enclosed spatial form, such as a tomb.

This study concerns itself with the way changes in materials and structural principles affected the structure-versus-spatial performance of columns and walls. The goal is to discover how columns and walls made of the modern building materials of concrete and steel have transformed the relationships that pertained in columns and walls of masonry or timber.

A study of the evolutionary building processes in Greek megaron building types and the Chinese timber-frame hall provide evidence of the structure-versus-space correlation as an important factor of the development of building form. The introduction of iron, concrete and steel during the Industrial Revolution engender the problem of coordination between the new building materials and the conventional spatial form. Experiments with the correlation between structure and space occurred with the advancement of the twentieth century, best examplified in the buildings of Le Corbusier, Louis Kahn, and Frank Lloyd Wright.

With a systematic analysis of the column system, wall system, and column and wall system, in conventional masonry and timber-frame buildings, the study leads to an examination of three modern building cases, Le Corbusier's Carpenter Center, Louis Kahn's Exeter Library and Gunter Behnisch's Lorch High School.

Conventional buildings were based on an orthogonal geometry in which the column and wall systems maintain a complementary correlation between structural and spatial form. In these buildings, the physical enclosure shaped by the walls, often, dominates over the virtual space suggested by columns.

A different approach is found in the three modern cases, which show a range of possibilities between the correlated structure-versus-spatial forms and the unrelated forms. In the former case, as found in the Exeter Library, the primary structure defines a correlated physical and virtual spatial form. The regular and symmetrical positional relationship between the solid and the void results in a coherent relationship between the structural parts and the spatial form as a whole. In the latter case, as found in Lorch High School and the Carpenter Center, the physical enclosure as a secondary structure shapes the predominant building form. The primary structure, of either columns or walls, often provides for a virtual spatial form. The physical enclosure may or may not support the virtual form of the primary structure. Furthermore, the physical enclosure may also shape virtual space, independent of the enclosure as a whole.

Layers of virtual spatial form thus are often a result of the unrelated spatial and structural relationship. In such a tendency toward virtual spatial form, the columns draw attention as important spatial definers, besides being structural agents, while the walls, especially non-bearing walls enclose space, but also attain their independent tectonic role.

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Chapter 1

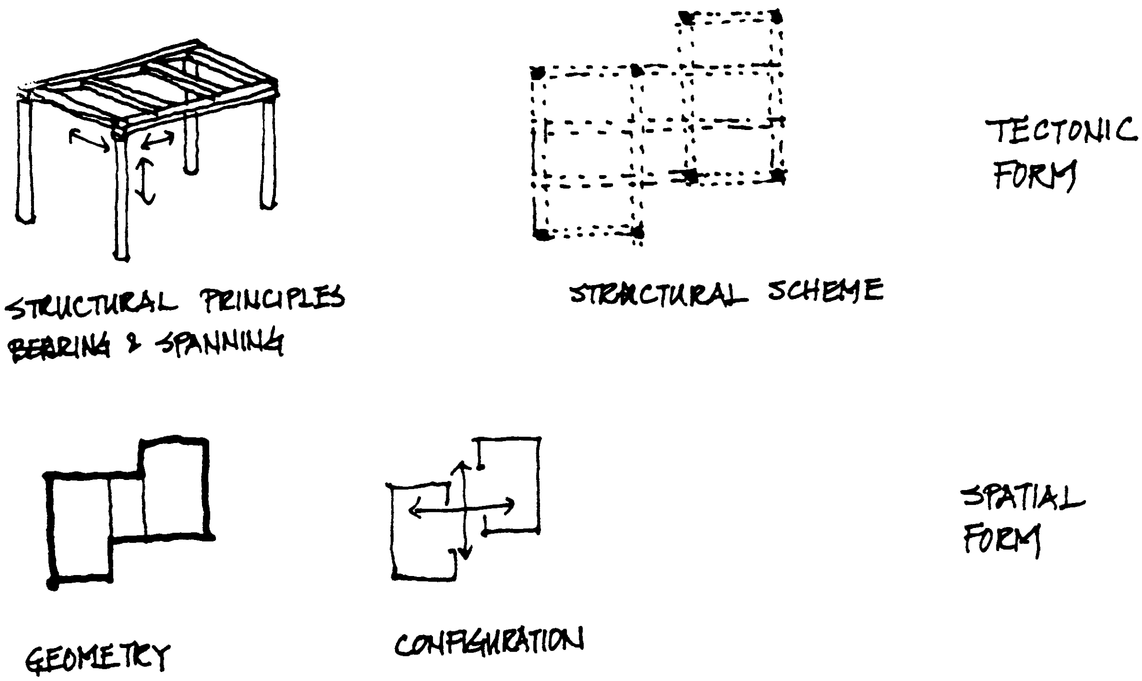
INTRODUCTION

The Framework

This thesis forms a study of the relationship between tectonic and spatial form, a dichotomy that emerges in the construction of columns and walls for buildings.

The study consists of an investigation of the tectonic versus spatial relationships of columns and walls in: a) conventional buildings of masonry and wood, and b) three buildings exemplifying distinct uses of modern building materials and structural principles.

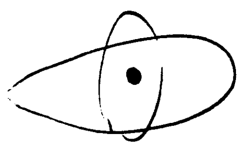
In the study, I look at two aspects of columns and walls as tectonic forms, namely the structural principles and the structural scheme. Structural principles refer to how the load-transfer mechanism - such as spanning, load-transmitting and load-resisting forces - relates to the shape and the configuration of the component parts of columns and walls. Structural schemes refer to the dimensions of columns and walls and their positional relationship in space. The study of such structural principles and schemes in forming spatial volumes helps to relate the tectonic nature of columns and walls to their spatial content.

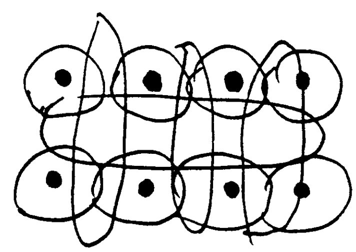


A spatial form is the three dimensional shape of spatial volumes defined by the structural elements and other construction materials. This spatial form involves two considerations in my thesis: The geometry, and the configuration. The geometry analyzes and synthesizes how a plan view of a building relates to the primary geometrical entity, octagons, circles, squares, rectangles, etc. By the configuration, I refer to the connection and positional patterns of spaces.

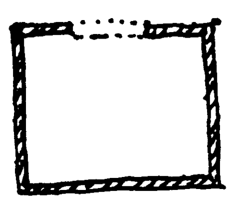
The tectonic form lies in the structural realm of the physical presence of a building, while a spatial form resides in the configuration of volumetric spatial geometries. This spatial form ranges among "virtually" suggested forms, "literally" defined forms, and "physically" confined enclosures.

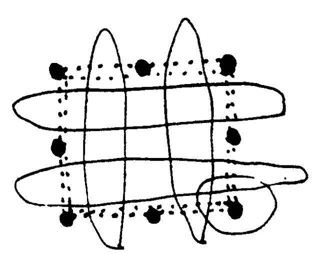
The three types of spatial forms are the key terms that will appear constently throughout the thesis. A virtual spatial form refers to the varied potential spatial forms suggested by a structural scheme, which is not constrained by one singular spatial definition. The varied shapes of radiating spatial form that surround a single column, or the simultanuous reading of bays and radiating zones among rows of columns are examples.





When the structural scheme starts to confine a space with roofs or floors, there emerges a literal definition of the spatial form. This literal form may, at one extreme, co-exist with the potential virtual spatial form such as an open pavilion; at the other extreme, it may become a wall enclosed physical spatial form such as a tomb.





Two rows of columns define a literal spatial form, at the same time suggest other potential virtual spatial forms. A space partially supported by walls and partially by columns may simultaneously suggest physical, literal and virtual spatial forms. Therefore, there are relative degrees of differences among the three types of spatial forms, instead of an exclusive distinction. The interplay between the tectonic and the spatial resides in the structural correlation with the three types of spaces as a continuum of spatial phenomena. A framework of the interplay between the tectonic and the spatial form can be set up as follows.

	TECTONIC	SPATIAL
ELEMENTS	columns and walls	volumes or void
FACTORS	structural: materials principles schemes: positions dimensions	geometry configuration
COMPONENT WHOLE	structural forms	spatial forms: virtual literal physical

Using the above framework, I first go through a general survey of the conventional column and wall systems in wood and masonry. To organize the survey, I classify the structural form into three categories, column system, wall system and column-and-wall system. This historical review of the conventional columns and walls provides an introduction to my investigation of three modern buildings, Le Corbusier's Carpenter Center, Louis Kahn's Phillips Exeter Library and Gunter Behnisch's Lorch High School. The three buildings represent three distinct ways columns and walls are constructed. The Carpenter Center built in 1960 in Cambridge, at Harvard University is a concrete column-slab structure with glass and

Behnisch's Lorch High School of 1982 at Lorch, Germany, is a combination of concrete column-beam structure and steel column-truss structure with brick and glass infill.

The Three Cases

The Carpenter Center is one of the cases where Le Corbusier extends his Domino idea. The relationship between structure and spatial volume breaks from the past and introduces a new design agenda. The walls as the major elements that confine the physical spatial form are partially free from the major structure, columns in spatial geometries, while often depending on the columns for support. The partial spatial independence between columns and walls poses new questions about the formal presentation of columns and walls and their positional relation in generating space.

Louis Kahn recreates the classical tectonic forms and spatial organization with modern materials, structural principles, and construction technology. His obsession with archaic building structure is manifested in his masonry wall at the Phillips Exeter Library, though the tectonic construction of Kahn's walls evolves beyond his historical models. A unique feature of Kahn's building, as a result of the wall structure, is the clear articulation of spatial volumes. The position of walls in creating these volumes sets the positional criteria for columns. His columns often play a minor structure-versus-space role, supplementing the walls both structurally and spatially.

Juxtaposition and complexity in material and construction are central features in both Behnisch's structural system and infill. Columns and walls, in his predominant glass framed buildings, can be simultaneously dependent and independent structural elements that overlay on each other with or without orthogonal relationship. His column system often frees from the conventional geometries and he elaborates on the exterior facade through layers of construction details which often provide independent structural supports as facade-walls. In these ways, Behnisch's concrete column-beam, or column-slab system in most of his latest designs shows a step beyond what Le Corbusier had advocated about columns and walls.

These three cases present a definition problem for columns and walls. Columns and walls, with the advent of modern technology, no longer retain the same formal character, or perform the same structural and functional roles as conventional columns and walls. Modern materials -- concrete, steel, and glass, etc., -- with their structural properties, address a different language between solid and void than did the conventional masonry structure. The opening of new possibilities for columns and walls because of construction with new materials, as compared with conventional columns and walls of masonry and wood, demands a reconsideration of the definition of columns and walls.

Chapter 2

COLUMNS AND WALLS, A DEFINITION PROBLEM

Conventional Columns and Walls

Columns in both Greek and Chinese cultures share the same three basic parts: a base, a shaft and a capital. These three parts in both cultures formally articulate the flow of forces from the roof to the floor. The torus-shaped base is a joint between the ground and the shaft; the shaft tapering at top, bulging around the center and bottom transfers load from the capital to the base. The capital, widened at top, accommodates the load from the beams. Various formal elaborations on the capital, the shaft, and the base in both cultures respond to the same principle of the transmission of forces. The joints, the capital and the base are no less important than the shaft, not only structurally but also visually. These joints express the contact between the horizontal members, the beams, and the vertical member, the shaft. This contact has to deal with directional changes, and stabilization of the beams and shafts, as well as load transference. The round or square capitals found in buildings of both the classical and Chinese traditions allowed for construction of a joint with beams from both the longitudinal and lateral directions. The shaping of three parts, the capital, the shaft and the base into one integral column thus constitutes the very basic concerns of the conventional columns.

Walls in both pre-classical Western and Far Eastern cultures, were originally associated more with enclosure than with structure. Walls in the form of textile, mat, and carpentry, and walls in the form of masonry stone are two wall types which have attracted the attention of the historians up to the present day. In the ancient Roman treatises such as that of Vitruvius, building walls did not receive as much investigation as columns, while in treatises of a later period, such as Alberti's walls as masonry structure were evaluated in a close affinity with the order of columns. The height, thickness, forms and proportions among the elements of the walls, that is, the foundation, cornice, aperture and the like, are important considerations in building walls. However, in contrast to the structural columns, no specific standards were established for the wall sections. The ordering of the parts of a wall, if any, is in most cases dependent on the columns with which a wall is associated strucurally, spatially, or decoratively. This was especially true during Roman and the Renaissance periods, when columns tended to attach to walls decoratively or at most as one piece of the bearing element. The juxtaposition of the Greek column and lintel system with walls and vaults was a specialty of the Romans. Walls and columns incorporated in various forms as one system challenged the conventional structural separation of columns and walls. In such combination, they are considered as one plastic mass that articulates the edge of one space rather than as separate structural elements that define varied spatial zones.

Columns and Walls, In Modern Materials

For buildings constructed after the Industrial Revolution, the definition of columns and walls becomes more elusive. Varied terms can be substituted for columns and walls, presenting different types of structural principles. The structural properties of the columns of a monolithic frame structure differ from columns used as props to support beams. Columns made of new materials, no longer carry a base and a capital and, in most cases, building structure can be solely column systems infilled with secondary light-weight materials which form the enclosure. In contrast to the column-attached-to-wall mass structure of the classical masonry convention which intends to enhance the articulation of the boundary of the space, column and steel supports can be all skeletal systems, with or without a light-weight enclosure, that reduces the presence of a spatial boundary.

For the purpose of this thesis, I shall use the terms columns and walls at the abstract level of spatial form. In other words, columns, in this paper, refer to vertical linear elements, and walls to lateral planar elements. Modification of this basic definition according to different material and structural principles will be addressed as needed in specific cases.

Chapter 3

COLUMNS AND WALLS AS FORMERS OF SPACE

Whether deployed as pure column or wall systems, or as compound systems of columns and walls, these structural elements may be assessed both in relation to material structure and the volumetric form shaped by the structure. The connection between these two phenomena, that is between structural principles and schemes in defining space, is one of the important factors that governs the evolution and the development of building forms through history.

The evolution of building materials and structure constantly changes the tectonic nature of columns and walls. This tectonic nature influences not only the shape and the configuration of the parts of columns and walls but also their dimensional and positional scheme in space. The formation of columns and walls and their spatial deployment generates structural forms which either physically enclose a space, partially define a space, or imply a virtual spatial form. These various formations of space in relation to the structural form can be assessed from the conventional building evolution.

Both the structural and spatial forms in the process of building development are guided and constrained by conventional building forms. We may argue that the interplay between structure and space either revolve around or evolve beyond the conventional building type. A building form can result from the maintenance of the structural convention, or the spatial convention, or a combination of both, despite the changes of materials and the structural elements.

The transformation of the primal building type in both Greek and Chinese cultures can illustrate this argument. "Primal building type" refers to the type of building form that was consistently adopted in several kinds of buildings, single-unit space, complex-unit space, and others, such as temples and palaces.

The Conventional Building Transformation in Greek and Chinese Cases

The tectonic form of columns and walls has a long tradition in Western and Far Eastern building cultures. Both ancient Greco-Roman and Chinese civilizations developed standards of building methods recorded in official documents. These documents developed into treatises which shaped the image of columns and walls built before the Industrial Revolution. In these sources, the structural elements were specified in terms of shapes, sizes, and their relational positions in space. Though in the Greek tradition, the dominant structural form began with timber and moved to a masonry structure, in the Chinese tradition it remained timber. In any case, in both cultures special attention has been given to the shaping of columns and walls as bearing elements.

From early documents about Greek architecture, we have sources such as the building inscriptions since the Hellenistic age[1], and a reflection in the organized Roman treatise of a later date, Vitruvius' The Ten Books on

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1 John James Coulton, Ancient Greek Architects at Work: Problems of Structure and Design (New York, Ithaca: Cornell University Press, 1977), pp. 52-66.

Architecture (c. 1st century AD)[1] . For Chinese architecture, we have "Kao Kung Chi", (考工記 translation: A Record of Craftsmanship) in the Chou Li, (translation: Civil Ordinance of Chou Dynasty, 1122-221 BC)[2] · Both these Greek and Chinese sources reveal that a standard of building was established. In most cases, these standards were followed and used by craftsmen for official and public buildings.

Most Hellenistic inscriptions to the builders specified structural elements; the spatial organization of the elements as a preliminary set of design decisions was not provided[3] . Plans and elevations were not used in this early period, so the architects had to work out details during construction. Thus there was no single correct proportion for these Hellenistic temples, although there was increasing regularization. As Coulton stated, "the archaic architecture shows less uniformity than later architecture both between one temple and another, and between identical elements of the same temple."[4] In the time of Vitruvius, a module was developed that systematically outlined the dimensional proportion of the structural elements as they define space. The concern with the dimensional relationship of structural elements as a system

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1 Morris Hicky Morgan, Tran., Vitruvius: The Ten Books on Architecture (New York: Dover Publications, 1960).

2 Yin Lin, Chou Li Chin Chu Chin Yi (Taipei, Taiwan: Taiwan Shang Wu Yin Shu Kuan, 1960).

3 Coulton, pp. 54-55, "The most important element seems to have been a technical description called the syngraphai--specifications--which set out the general lines of the building with a good deal of detail on the way it was to be built. The information given there might be supplemented by further details in the individual contracts--also called syngraphai--specifying the work undertaken by each contractor. . . . There is no reference to drawings, plans or elevations in syngraphai of either type; . . . The necessary detail is instead conveyed mainly by measurements and by technical terms such as 'triglyph or 'Ionic cornice'. . . . where special detail was required, the architect would supply a paradeigma . . . The meaning of paradeigma is clear-a specimen- . . ."

4 Coulton, p. 66

in organizing space later became the basic framework for designing buildings that followed the Greco-Roman convention.

Contrary to the ancient Western sources, the Chinese source "Kao Kung Chi" (考工記) did not provide a clear specification about individual structural elements. Its prime concern was the dimensional and the positional relationship among spaces. It was not until the Sung dynasty (960-1126 AD) that a thorough treatise, "Yin Chao Fa Shi" (營造法式 translation: The Model of Building Construction), on building methods was published by the government. It detailed classifications and definitions of structural elements along with their manufacturing and construction methods[1] . This Sung treatise showed continuity with the Chou treatise, "Kao Kung Chi" (考工記) in its concern with the proportional dimension in locating structural members in space. The general building principle in the Sung treatise was carried on during the Ching Dynasty (1644-1912 AD) by another important official treatise, "Ching Shih Yin Chao Shuan Li" (清式營造算例 translation: Construction Measurement of Ching Type)[2] . In both Sung and Ching treatises, the method of deciding the varied spatial units was systematically related to the dimension of the bracket system, a structural member. The structural element used for reference is not the important supporting or spanning elements but an intermediate one, relating support and span. It is also a unit that one does not mark out on the ground, as one would in locating columns (with or without a drawn plan). It implies a three dimensional conception of the building and its elements. In other words, spatial dimension

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1 Liang-ssu Chen, ed., Yin Chao Fa Shi Chu Yi, Vol. 1 (Beijin: Chung Kuo Chen Chu Kung Yen Publisher, 1980).

2 Yu-Yeh Chen, Chin Shih Yin Chao Shuan Li, Chi Che Li (Taipei, Taiwan: Shang Wu Yin Shu Kuan, 1960).

was consistent with structural dimension. The choice of structural and spatial dimensions depended upon building types.

Some early twentieth century buildings and their written records indicated that for more than 2000 years the same architectural practices prescribed by Chinese building treatises have been maintained.

The continuity of an established standard of building through centuries is also a historical phenomenon of the buildings following the Greek tradition. Numerous treatises, especially those of sixteenth century Italy, enrich Vitruvius' study of the classical architecture derived from ancient Greece.[1]

The persistence of a certain structural and spatial grammar in constructing buildings may lead us to investigate the primal type that started the convention.

According to Wycherley, at the time he wrote How the Greeks Built Cities, it was still impossible to define the basic types and variations of Greek houses[2] . The archaeological findings of various ancient Greek sites showed that a variety of house forms existed, among them, the megaron, which is of interest to the present study. The recurrence and adaptation of the megaron form in Greek temples, palaces, and complexes of courtyard houses suggest its importance both as a structural device and in spatial performance (fig. 3-1, -2, -3).

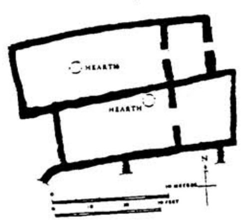

fig. 3-1 Plan of houses of begining of Trojan culture, Thermi I

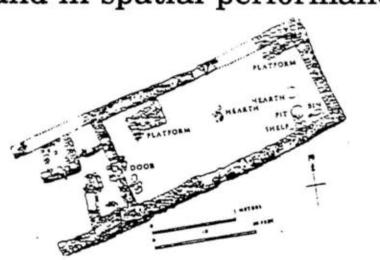

fig. 3-2 Plan of houses of Ib, troy

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1 Dora Wiebenson, Architectural Theory and Practice From Alberti to Ledoux (Charlottesville, Virginia: Architectural Publications, Inc., 1982).

2 Richard Ernest Wycherly, How The Greek Built Cities (London: Macmillan & Co. LTD, 1949), p.115.

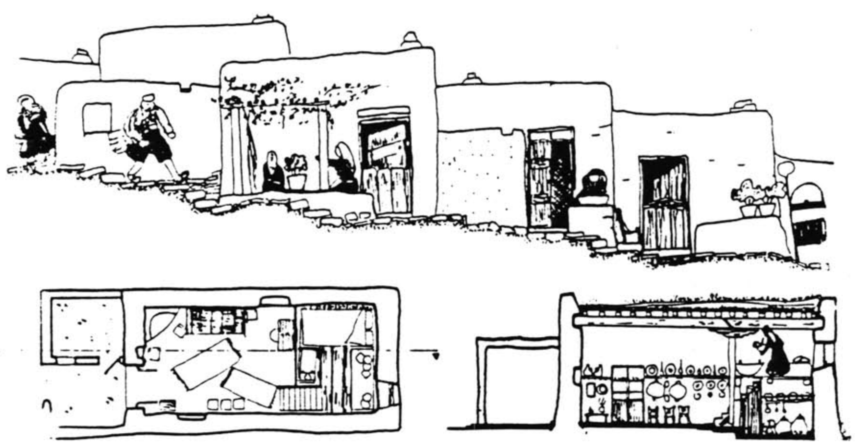


fig. 3-3 Megaron Houses, plans, sections, and front elevation

The exterior wall of a Greek megaron made a most direct statement: a house of a single longitudinal space. With the entry porch at one of the narrow ends, a megaron suggested two basic interior zones, the front access space and the back private space. The conception of a megaron form as two sections persisted throughout history, often reinforced by one or two columns located at the axial center.

The inherent nature of the longitudinal field of a megaron was recognized in the structural development of the megaron form as a temple (fig. 3-4, -5).

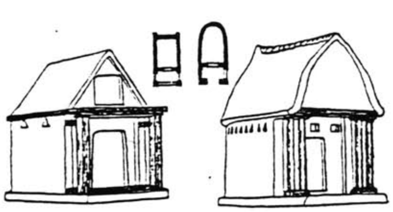


fig. 3-4 Restorations of model temples from Argive Heraeum and Perachora

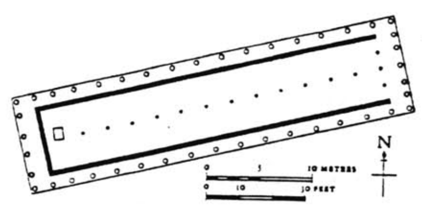


fig. 3-5 Restored plan of First Heraeum, Samos

Since the image of the temple deity took up only the space at the end of the far back wall, the main hall focused on directing attention toward the deity. The further elongation of the megaron form with the addition of more longitudinal columns, and the departure of the single row of longitudinal columns into two (fig. 3-6, -7), all revealed a realization of the structural implementation for literal spatial uses. This structural and spatial correlation was also demonstrated by the reinforcement of interior walls as structural elements. The addition of the interior walls to separate the interior space evolved from spatial needs. The recognition of the important structural performance of these walls pushed the evolution of interior walls toward a literal structural function as well (fig. 3-8, -9).

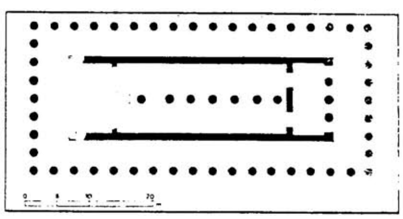


fig. 3-6 First temple of Hera, Paestum. c. 550 BC.

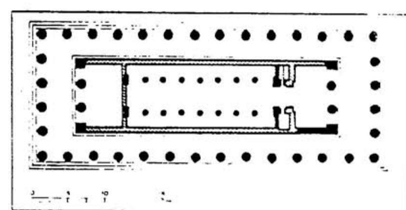


fig. 3-7 Second temple of Hera, Paestum c. 450 BC.

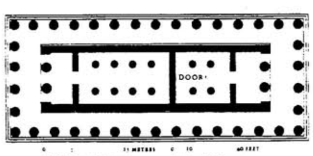


fig. 3-8 Temple of Apollo, Corinth

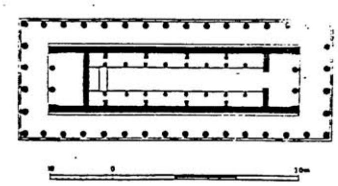


fig. 3-9 Temple of Hera at Olympia

Breaking away from the conventional spatial form depended on a reconsideration of structural deployment in space. The new spatial function influenced the pattern of change, which however is still guided by a concern with conventional building form. Thus, the spatial conception of building form and the structural nature of built form interact with each other in the transformation of a structured space.

The Chinese cases below further illustrate the correlational pattern between structural and spatial form.

Columns, functioning mainly as structure, were the basic constituents of primitive Chinese structural form. The walls in these buildings generally enclosed space, rather than supporting the roofs (fig. 3-10).

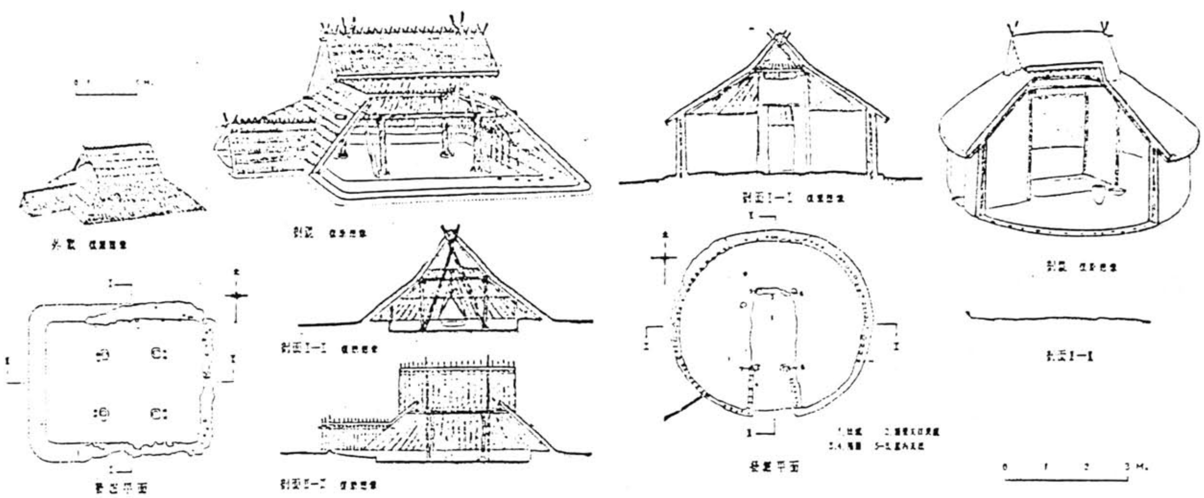
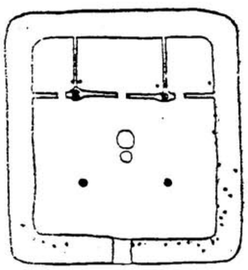


fig. 3-10 Primitive Chinese Houses, Sian, Shan Hsi

The columns of the early building type did not present a regular positional dimension among them. They suggest virtual spaces rather than defining literal spaces. However, as the number of columns multiplies, they are standardized in space (fig. 3-11, -12).



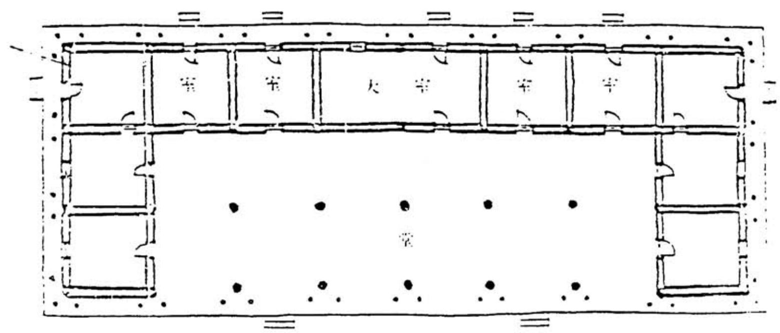


fig. 3-11 The Community House, Pan Po, Sian

fig. 3-12 Restorations of a Palace Hall, Yen Shin, Yeh-li Tou

This standardization, based on simple, repetitive structural bays, focuses on the variation of intercolumniation. Spatial variation remains mostly dimensional, rather than that of the geometrical and configurational pattern. (This mostly applies to the official houses, temples, and palaces, and not to the vernacular buildings.) The varied dimensional needs in space are modifiers of the column system. Thus, on the one hand, the columns shape a literal spatial form, on the other hand, spatial variation modifies the column system. This interaction between columns and space happened within a standardized building method. The interaction helps to enrich this standardized convention, instead of progressively breaking away from convention (fig. 3-13).

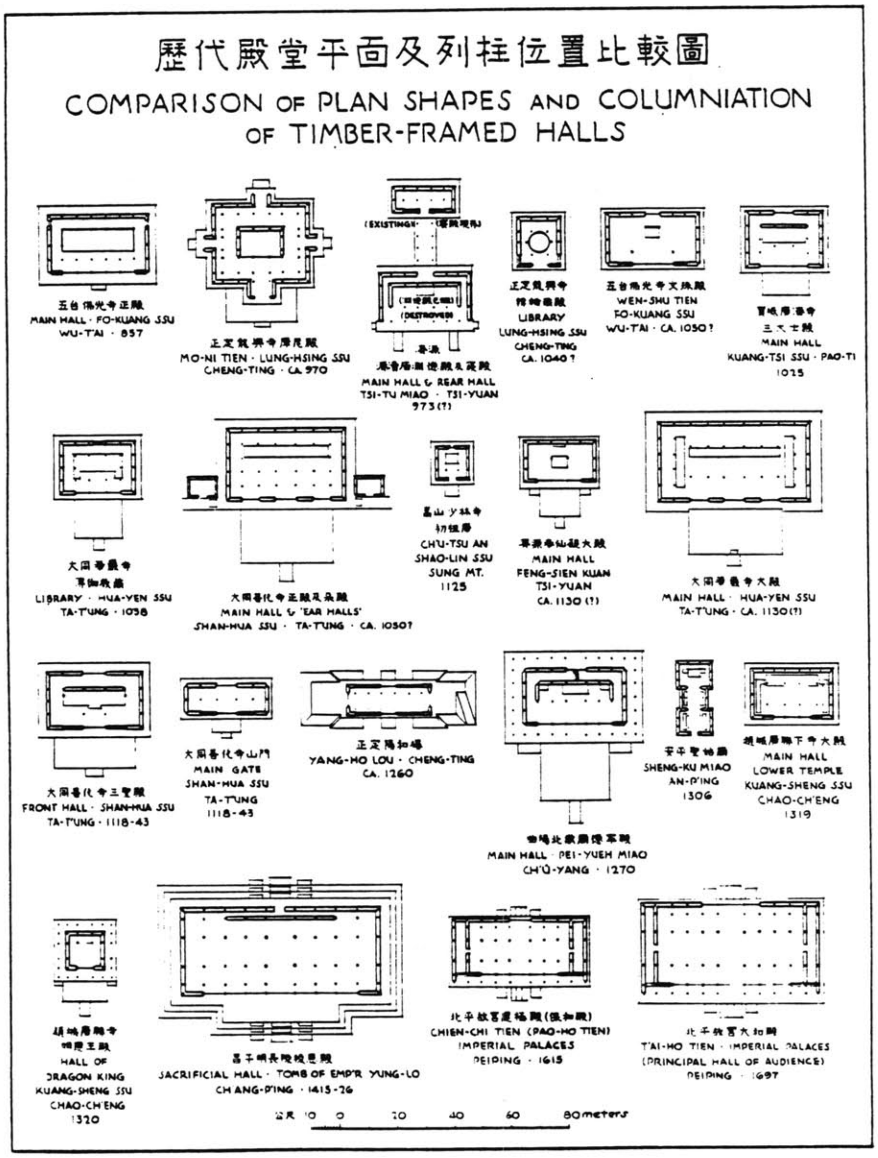


fig. 3-13 Comparison of plan and columniation of timber-frame halls

Conventional examples show that during the primitive stage, the demand for certain types of functional space had no direct relationship to the internal structural properties of the materials. As certain structural forms became the norm, the conception of the structural forms as established spatial form start to be formed. Each type of building form in history carried a double possibility: the structural nature could develop into a new spatial convention or it could adapt to the preceding spatial conception.

Two important phenomena exist in this evolved interaction between structural and spatial form. One is a direct transplantation of conventional spatial form onto the new structural form. The other phenomenon was a direct transplantation of the conventional structural form onto the evolved spatial organization. The two phenomena sharpened during the Industrial Revolution when concrete, iron, steel and glass emerged as possible new building materials.

The Industrial Revolution, New Materials and Conventional Building Forms

The first problem of the new materials and structural form is the conflict between the conventional understanding of columns and walls as structural elements and the structure-versus-space potential of the new materials.

During the Industrial Revolution, iron - and later steel and concrete - shaped according to conventional structural form is often the common solution, despite the structural nature of these new materials. The long-span potentials of these new materials were generally shaped in analogy to vaults, arches, or domes. Concrete and steel columns were often shaped in imitation of the Greco-Roman order, molded with vertical fluting and carrying Doric, Ionic, or Corinthian capitals, though in distorted sizes and proportions. The formal character of concrete and iron thus was constructed either by analogy to the masonry structural form or in imitation of it.

De Baudot's Church of St-Jean de Montmartre (1904) in Paris[1] is a case where concrete as rib-frame for the brick infill is constructed on a Gothic spatial typology (fig. 3-14).

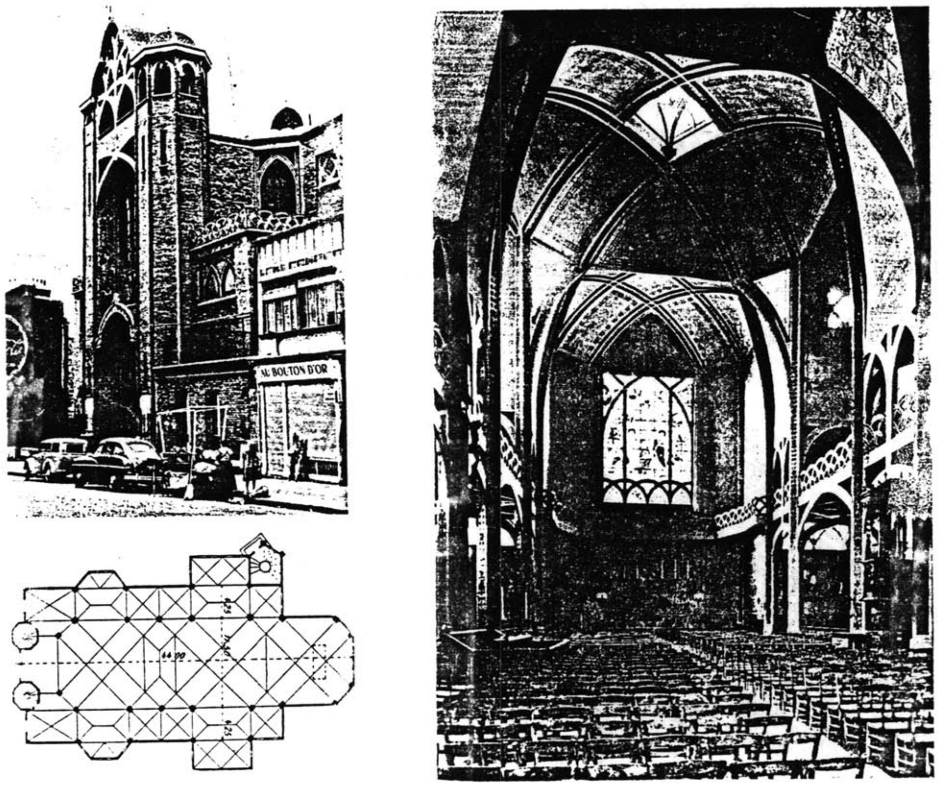


fig. 3-14 The Exterior, plan, and interior view of St-Jean de Montmartre

The concrete formed in continuous strips substitutes the conventional piers, buttresses, arches, vaults, ribs, and window frames that comprise a Gothic church. This concrete frame structure thus does not imitate the constituent structural parts, but the general formal features that constitute the Gothic church as a whole. The structure device recognizes the distinction between masonry and reinforced concrete construction, while building on a similar spatial deployment of the column scheme and the geometry of the Gothic plan.

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1 Leonard Benevolo, History of Modern Architecture, Vol. 1 (Cambridge, Mass.: MIT Press, 1977)

The result is a Gothic typology confined by a two-dimensional planar surface. The tectonic form of the concrete reveals the molding of a plastic enclosure of the brick infill, which advocates the airy lightness of the building form as a whole, instead of a tension between the soaring vaults and the heavy colonnades as we find in conventional Gothic churches.

Henri Labrouste's Bibliotheque Sainte-Genevieve in Paris (1838-50) is a case where slender iron columns in the style of the Corinthian order, and iron trusses in the form of arches define an interior space enclosed by a masonry structure (fig. 3-15).

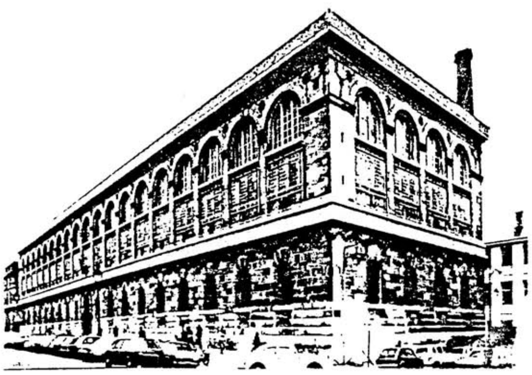
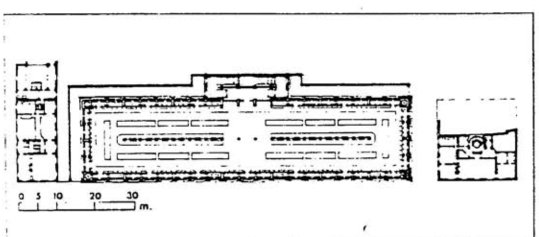
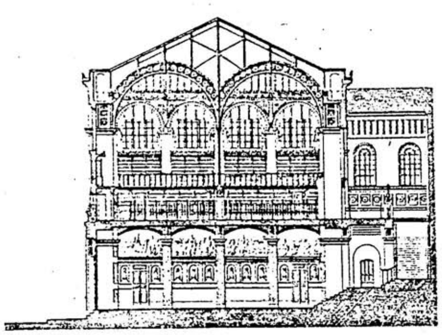


fig. 3-15 The exterior, plan, section, and interior views of Biliotheque Sainte-Genevieve in Paris





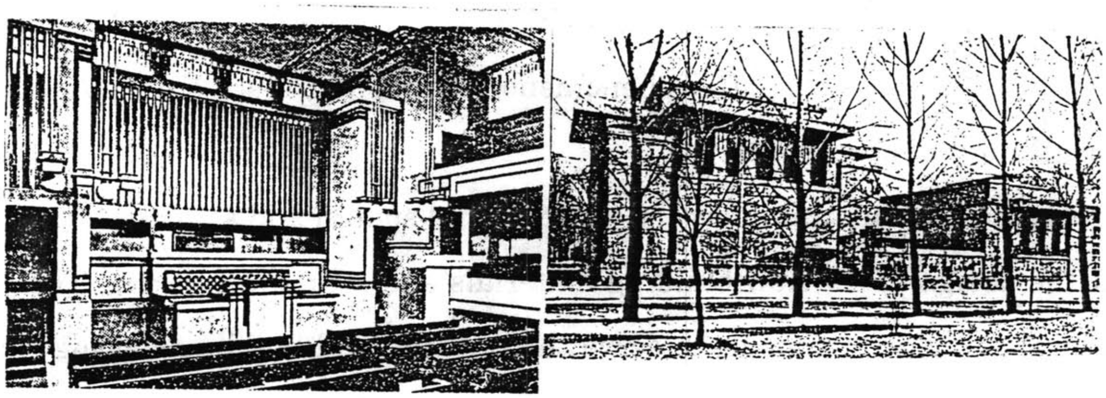
Here, iron, one of the new materials, is formed in imitation of classical columns, both in the component parts and the structural scheme, at the same time introducing a new spatial phenomenon which addresses transparency and continuity of open space.

The two cases illustrate how the conventional spatial and structural form affect the design of the new building materials and structural forms. The new structural elements are made to serve the conventional building typology and volumetric form, while, in spite of the persistence of the conventional building form, new spatial phenomena are engendered. In other words, either the structure or the space may retain characteristics of the earlier precedents, while the composed structure versus spatial relationship as a whole changes. The realization of the new spatial phenomena aids our understanding of the spatial meaning of the new materials and structures.

The Modern Period, The Coordinated Exploration Between Structure and Space

The turn of the twentieth century brought with it a search for new building forms coordinated with the inherent structural properties of new building materials. Columns and walls, as structural elements, evolved beyond imitation of classical order and conventional building typology.

Frank Lloyd Wright's Unity temple in Oak Park, Illinois (1906), shows how poured concrete was used for both columns and walls (fig. 3-16). It is basically a wall enclosed space with heavy concrete columns symmetrically positioned at the four corners of the interior. The spatial geometry follows the classical



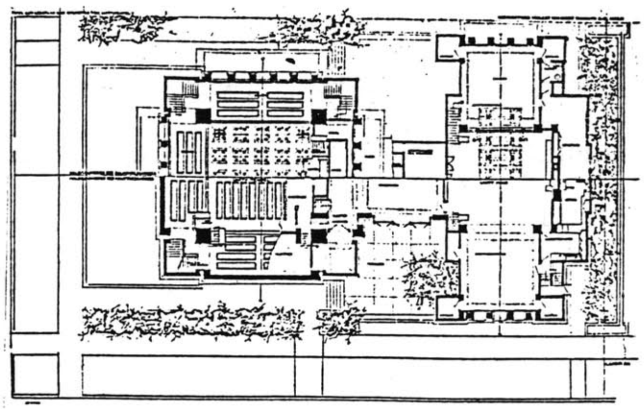


fig. 3-16 Interior, exterior and plan view of Unity Temple

type, while the poured concrete generates a new structural form. This new structural form consists of two distinct structure-versus-space attributes of poured concrete.

The first is the possibility of molding the walls as monolithic unit-walls enclosing space. These unit-walls are free from the boundary of the roofs and the corners of the enclosed space. The freedom generates planar walls as the structure that defines the major served space. The planar walls allow possible variations of the size and locations of openings for lights and for circulation. The spatial result breaks up the conventional box form of masonry structure.

At the other hands, the molding of the walls allows for L shaped or U shaped containment walls that define the service space such as the staircase. These containment walls, instead of being composed of small units of single stones or bricks, are a solid spatial form. Both planar walls and containment walls of poured concrete are solid monolithic pieces, individually defining virtual space and together forming a complex physical enclosure.

The second structural feature is that the columns are shaped with the same molding technique as the walls, showing a stronger material and formal continuity with the walls than that of conventional columns and walls. This structural continuity between columns and poured concrete walls is enhanced by a symmetrical correlation between columns and walls in defining units of space. The columns, either growing upon the walls or on the separate structural lines from the walls, reveal a continuous response to the formal character of the walls. These columns are thus more an outgrowth of the wall than a separate structural element in space.

These two structural attributes affect the spatial form at Unity Temple, which follows conventional symmetrical spatial typology, but differs from conventional volumetrical form in that the space is formed by the monolithic modular units of concrete plane walls or containment walls compiled to make a whole. The parts and the whole are clearly articulated as modular units both spatially and structurally. These spatial possibilities in relation to the poured concrete generate a new building form which goes beyond the conventional type in the structure-versus-space relationship.

The use of iron and steel as the principal structure, which developed into a new spatial form which flourished in Chicago, is best represented in the office and department buildings built at the time. Here, the exploration of metal focuses on the framework quality of the materials. This steel framework generates box-like spatial volume with a physical enclosure at the exterior perimeter (fig. 3-17).

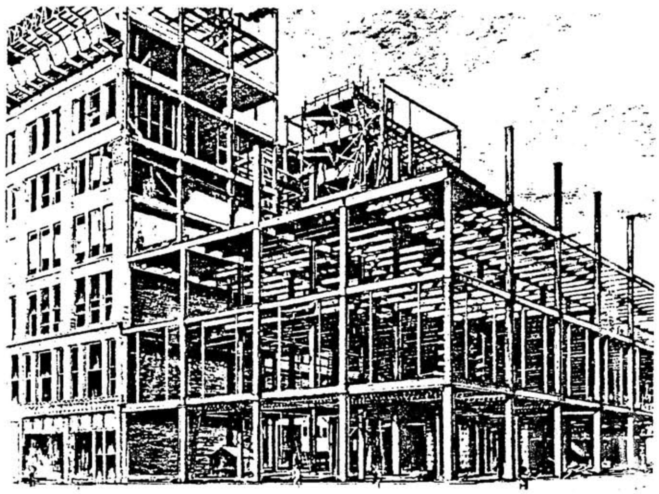


fig. 3-17 Fair Store, Chicago, 1889-90

The box-shaped spatial geometry and configuration become the typical structure-versus-spatial form that is associated with buildings adopting the steel frame. The subdivision of spaces are relegated to the secondary structure. We may say that the steel frame developed at Chicago conveys only one typical spatial form, that of a continuing growth of box units. The virtual form of the steelframe and the physical enclosure coincide as one neutral ground on which interior subdivisional space may occur[1].

The separation of the physical spatial form from the virtual structural form is best represented in Le Corbusier's experiment with his theory of five points[2]. In the theory, Le Corbusier proposes the use of a support structure, often composed of regularly placed columns, as the ground on which spatial

1 Colin Rowe, "Chicago Frame", in The Mathematics of the Ideal Villa and Other Essays (Cambridge, Mass.: MIT Press, 1976), pp. 90-117.

2. Stanislaus von Moos, Le Corbusier, Elements of a Synthesis (Cambridge, Mass.: MIT Press, 1979), pp. 69-141.

enclosure performs an independent spatial defining role and asserts the major formal character for the building as a whole.

Those of his buildings which are structurally akin to the five-point principle present a wide range of spatial typology and formal shapes. The non-bearing enclosure is either parallel with the geometry of the consistent column grids, as in the houses at the Weissenhof Siedlung, Stuttgart (1927, fig. 3-18), or is formed into curves, contrary to the geometry of the column grids, as found at the Villa Stein, Garches (1927, fig. 3-19). The latter either plays in smaller scale within a general orthogonal outer form, or performs the major exterior volumetric forms, as in the later Carpenter Center at Harvard University (1964). The interior and the exterior forms of different parts of the building can be varied. In some cases, these interior volumes become the exterior form; in other cases, they are independent from a continuous exterior facade. In the latter case, a reading of the varied spatial zones can take place when we take a promenade in the interior as at the Villa Savoye in Poissy (1929-31, fig. 3-20).

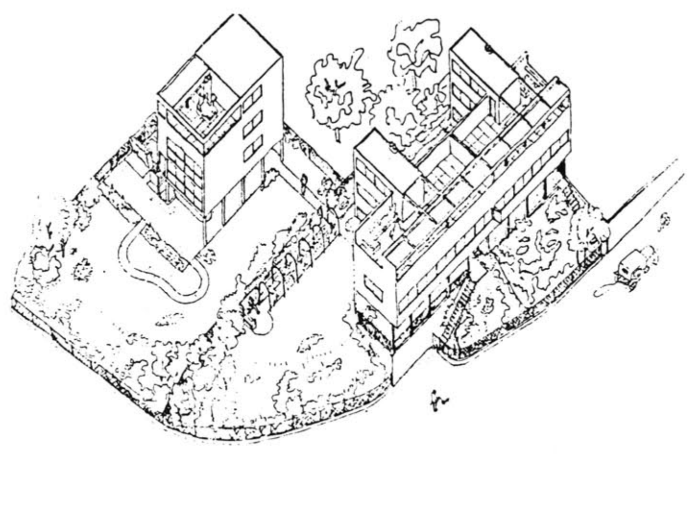


fig. 3-18 Weissenhof Siedlung, Stuttgart

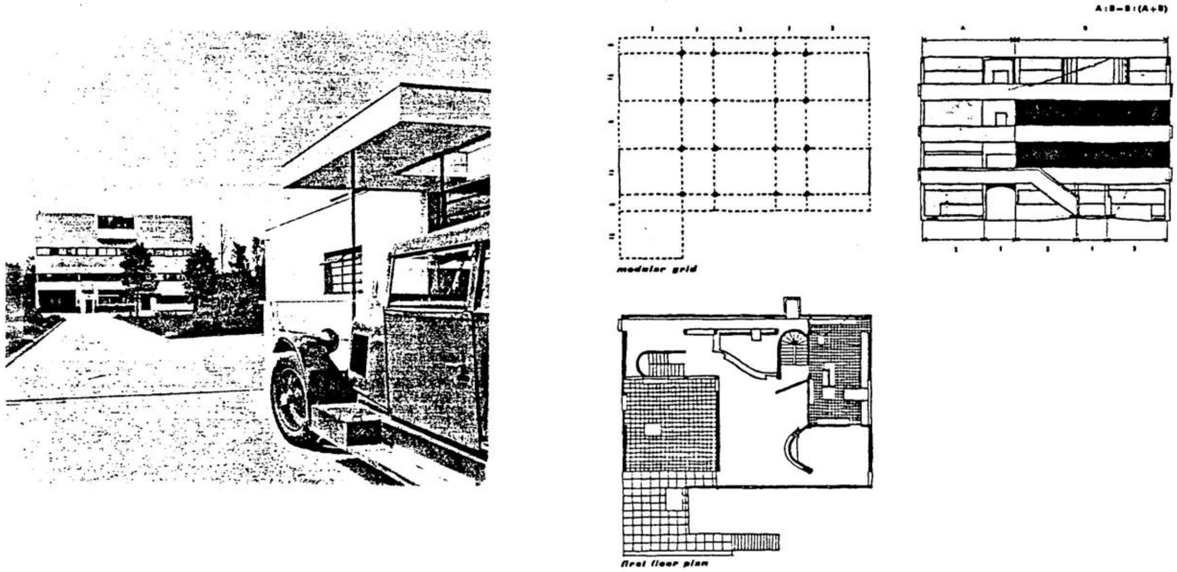


fig. 3-19 Villa Stein, Garches

La villa est entourée d'une ceinture de futaies

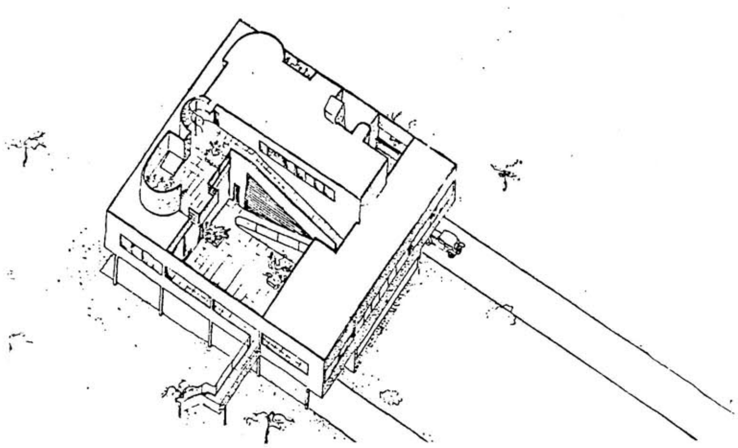


fig. 3-20 Villa Savoye, Poissy

The columns as structure in these cases are almost consistently placed in orthogonal grids. The non-bearing enclosure becomes the dominant spatial form distinguished from the bearing structure. Different from the Chicago frame, Le Corbusier's column structure is not a neutral grid system, and the relationship between the structural and the physical enclosure is not clearly expounded in all of his buildings. A variation of the dimensions among the columns is often considered in light of the spatial typology as in the case of Villa Stein-de Monzie at Garches. In this building, the virtual form of the structural variation is reflected through the facade device or by the spatial division of the secondary enclosure[1].

From the above examples, we see that the use of new materials and structures affected spatial geometry and configuration patterns. The versatility of these new materials in generating varied spatial forms is much greater than that of conventional materials. One important reason for the change is that the basic structural elements of columns and walls have changed drastically not only in their structural properties, but also in the formal character as a result of these structural properties. With a prior understanding of the structure-versus-space relationship in conventional columns and walls, a recognition of the new possibilities of columns and walls in modern materials may surface. Chapter four serves such an intent.

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1 Colin Rowe, "The Mathematics of the Ideal Villa", The Mathematics of the Ideal Villa and Other Essay (Cambridge, Mass.: MIT Press, 1976), pp. 1-27.

Chapter 4

COVENTIONAL COLUMNS AND WALLS

Columns and Walls as Singular Structural Form

Columns and walls as singular structural forms do not explicitly demarcate or enclose a space. Rather they are free-standing spatial objects which suggest potential virtual spatial forms.

Columns

The structural and visual demand on a Greek masonry column with three components suggests that spatially a column has to be free-standing from the base to the capital without interruption of walls or floors (fig. 4-1). Each column is not just one of a set of columns to support the roof but also an individual spatial object by itself (fig. 4-2). Thus besides suggesting bays of literal spatial form, each column of the set of columns marks a point in space, from which radiates a circle of space.

The single masonry column of monumental size is an important symbolic device. In towns and cities, from Greco-Roman times to the present day, free standing columns, often set on pedestals marked events, celebrated places, or memorialized important persons (fig. 4-3). The free-standing column in an urban context is either dependent on the surrounding buildings in a spatial configuration as found

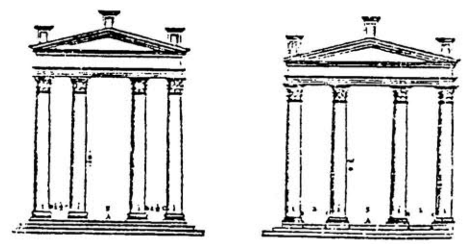


fig. 4-1

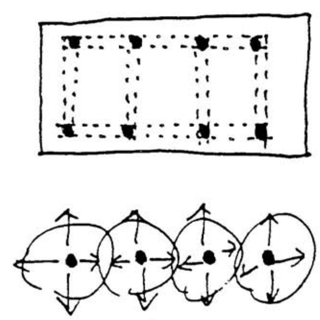


fig. 4-2

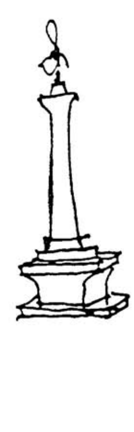


fig. 4-3

in most of the Greek forums, or asserts a central position as in some Roman and Renaissance squares.

In an asymmetrically positioned building cluster, the distance between columns and buildings, and between columns is the clue for the demarcation of spatial zones (fig. 4-4). A symmetrically organized building cluster suggests a field of orientation in relation to the location of columns (fig. 4-5).

Two columns within a certain proximity mark off a spatial zone. We differentiate the space between the two columns from the space beyond the two columns depending on the distance between them in relation to the surrounding spatial objects. Each of the two columns occupies a spatial domain and generates a circle of space about it, which, if the columns are not too distant from one another, is subordinate to the circle of space generated by both columns (fig. 4-6). A lintel or beam atop two columns establishes a free-standing gate (fig. 4-7). Again, as in the case of one column, a free-standing gate is more a symbolic device than a structural one. This symbolic nature is presented through the spatial intention. Two columns mark a line, extending in one direction and implying a division between one side of the gate from the other side. A free-standing gate is metaphorically a mark of passing or entering from one place to another, though physically the two places are actually the same open space.

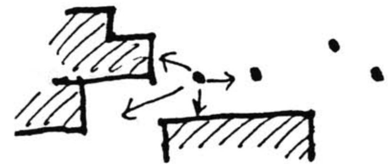


fig. 4-4

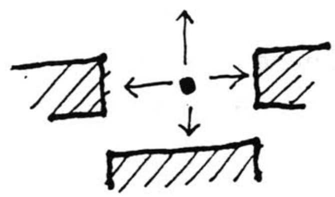


fig. 4-5

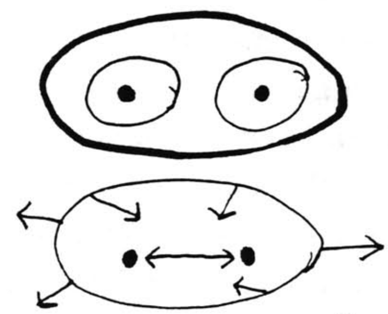


fig. 4-6

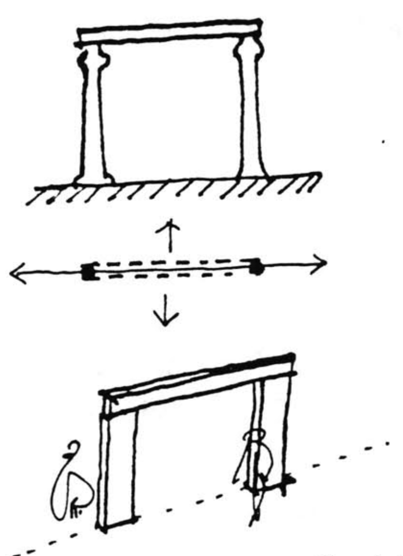


fig. 4-7

This juxtaposition of the physical and metaphorical association creates a play which lies in the realm of performance, of ceremony.

The free-standing gates are present as parts of urban or landscape form in both Western and Far-Eastern countries. Columns in forming a free-standing gate tend to resemble walls. These gates define the entry of a house, a garden, a city block, or a city. The Western masonry gates of monumental scale relate more to walls penetrated with openings than to columns that define openings. Columns on these walls are decorations attached to the masonry mass (fig. 4-8). The Chinese wooden street gates are screen structures in which the columns serve to support a framework of beams (fig. 4-9). Columns as points in space invite lateral extension surfaces to enhance or to explicate the lateral demarcations. This lateral directional extension is the very spatial feature with which a wall is identified.

fig. 4-8

fig. 4-9

Walls

Walls as two-dimensional spatial forms are barriers. The lateral width of the wall can be so narrow that within certain lateral dimensions (approximately three feet or less), it participates in the character of a column, generating a circle or an ovoid of space about it, more forcefully than it demarcates two more forcefully than it demarcates two territories at either side (fig. 4-10). The differentiation between columns and walls as a spatial form is thus ambiguous. The transformation between columns and walls can be viewed in terms of an exchange between solid and void. On the one hand, a wall is formed with an increasingly dense array of points in the void; on the other, columns are formed by the penetrations in the walls (fig. 4-11). In the former case, solids grow and occupy space, as for example, the Western masonry street gate or arcaded colonnade which originates from column dimensions and grows towards wall dimensions (fig. 4-12). In the latter case, the openings grow larger until the interior arched walls of a Romanesque church change into the colonnade of the later Gothic church (fig. 4-13).

The lateral dimension of a wall in relation to the size of the human body affects the directional field of the projected spatial precincts thus demarcated. Two types of spatial implications occur when a wall extends beyond five or six feet. On the one hand, it generates two territories on either side of the wall; on the other hand, it generates a direction of movement parallel to the wall (fig. 4-14). The former case is general to any wall long enough to avoid the ambiguous relation to column already discussed. The latter case applies to elongated walls, when, at a minimum, the length of the wall exceeds its

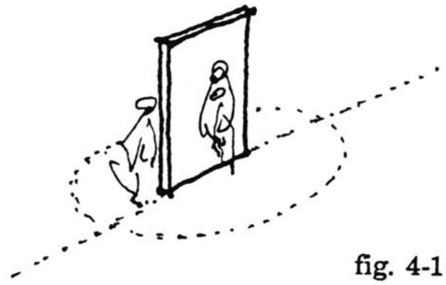


fig. 4-10

fig. 4-11

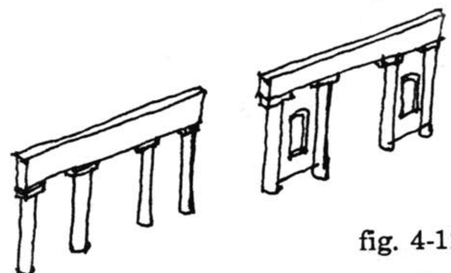


fig. 4-12

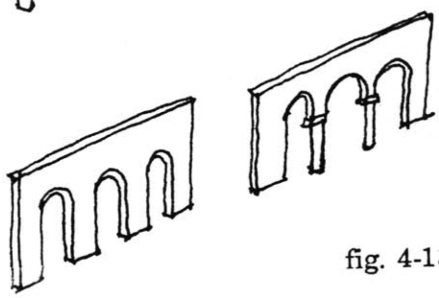


fig. 4-13

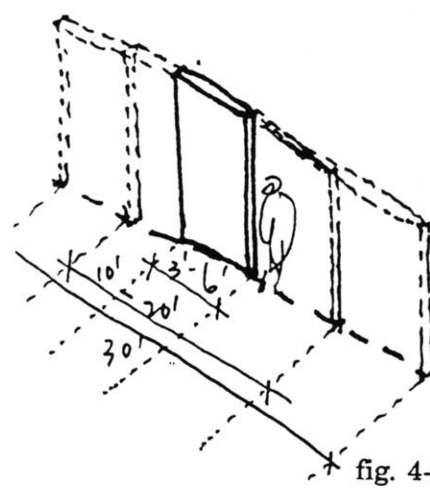


fig. 4-14

height. The space around the walls then becomes more a parallel directional path than a projected territory, or perhaps both.

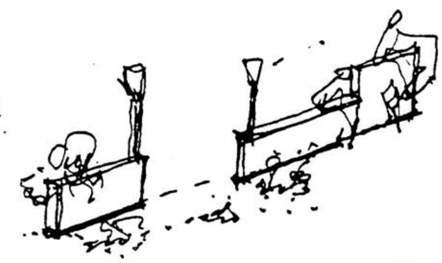
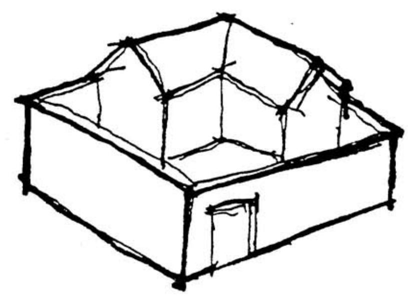


fig. 4-15

Walls can be low walls with height of about four feet or less, and thus not obstructing vision, or high walls which control visual access. In an open space, free standing walls demarcate an area related to either the landscape form or to the surrounding buildings. The low walls appear often as garden walls dividing areas while retaining visual continuity of the landscape (fig. 4-15). The high walls are often used to confine a house, city block or city (fig. 4-16).



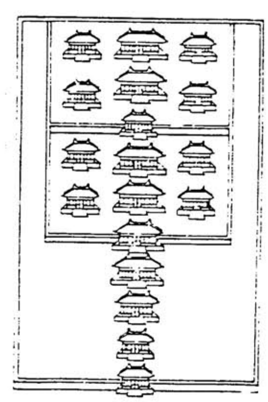


fig. 4-16

The materials and the thickness of the wall in relation to the height are critical considerations in shaping and stabilizing the wall. The solidity of stones or bricks in self-stabilization establishes them as the most widely used materials for free standing walls. There are two basic ways to stabilize these masonry walls. One is to widen the base as in most cases of city walls (fig. 4-17), the other is to bend or curve the lateral surface of the wall as in the Great Wall at China, or, at a small scale, in Jefferson's garden walls at the University of Virginia (fig. 4-18).

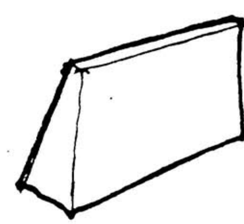


fig. 4-17

fig. 4-18

An important attribute of these free-standing masonry walls is the generation of openings or spaces in the walls or the transformation of the continuous mass toward the column dimensions. Habitable space can be created with a wall of an adequate thickness, as if carving out a three-dimensional space from a built form that is conceptualized two-dimensionally (fig. 4-19).

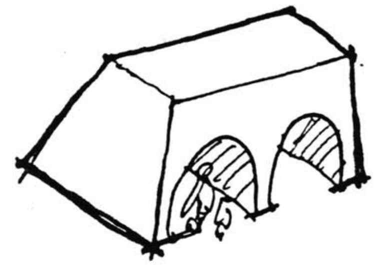


fig. 4-19

Columns and Walls as Literal Structural Forms

Columns and walls arrayed three-dimensionally enclose or define space and at the same time, usually support a roof. The following study differentiates this three-dimensional array into three categories of structural systems: "columns", "walls", and "columns and walls".

<u>Column System</u>

Two important structural attributes that relate columns as structural forms to space are the size of columns and the joint pattern between beams and columns. The size of columns relates to the spatial proximity among columns (fig. 4-20) and the joint relates to the geometry of the spatial layout of columns (fig. 4-21). Columns which form a three dimensional array differ from those forming a two-dimensional array in the joint pattern between beams and columns. Columns of a three dimensional array have to deal with at least three directions of load transfer, one vertical and two horizontal (fig. 4-22). Often, different sizes of beams are laid out in different directions and perform a hierarchy of load-transfer relationships. Columns, in most cases, are in direct contact with the primary beams. The possible direction of the beams form columns into various geometrical shapes, though arbitrary shapes of columns in relation to beams may sometimes occur (fig. 4-23). Accordingly, the joint pattern between beams and columns has to deal with the directions of the beams, the hierarchy of beam order and the shape of columns and beams.

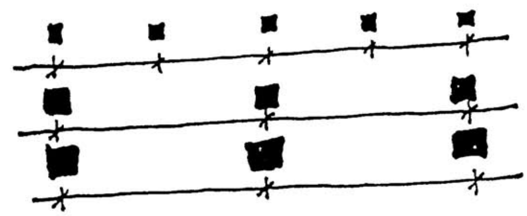


fig. 4-20

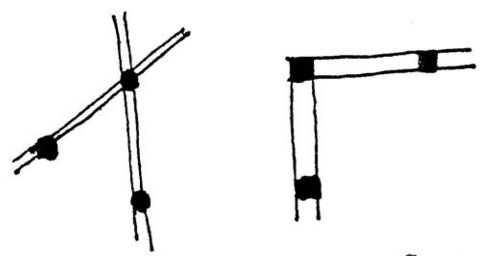
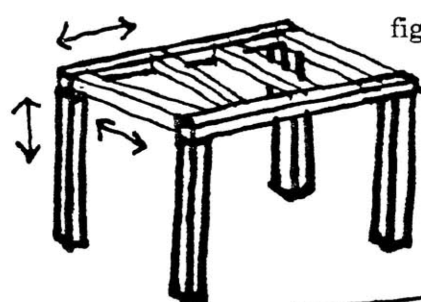


fig. 4-21

fig. 4-22


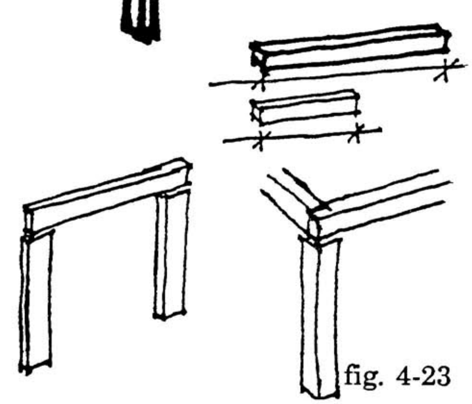


fig. 4-23

In early building development, the bearing role of columns for roofs and floors overrode their other roles. Columns' spatial relationship is subservient to their function as a roof support. Their relational position in space is, in most cases, a structural decision. Their component parts and the shape of these parts as a whole relate more to the structural principle than to the spatial intention. However, the structural principle and scheme of these columns can be related to a virtual spatial volume, and subsequently may affect the physical spatial form (fig. 4-24). As the building enterprise matured, the dimensional needs of space influenced the decisions for the choice of the size and location of columns (fig. 4-25).

The spatial definition of the column system does not necessarily correspond to the spatial form of a building. The presentation of the physical spatial form depends on the continuous surface of walls. This continuous surface may relate to the column system, while not necessarily corresponding to its spatial layout (fig. 4-26). Nevertheless, in conventional buildings of both the West and the Far-East, the physical spatial form supported by column structures often follows the virtual form of the column system. This applies especially to the monumental buildings such as temples and public halls. The Chinese timber-framed hall, Greek temples, Roman basilica, and mosques are examples. The walls in these examples

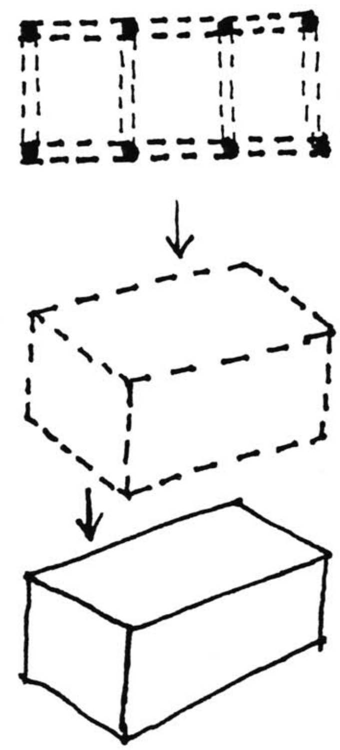


fig. 4-24

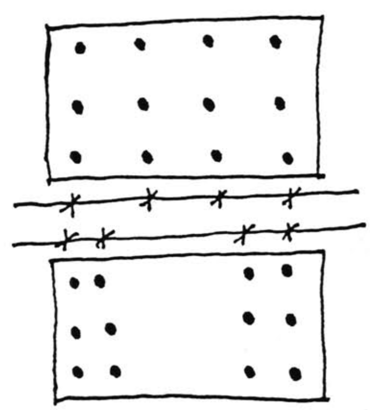


fig. 4-25

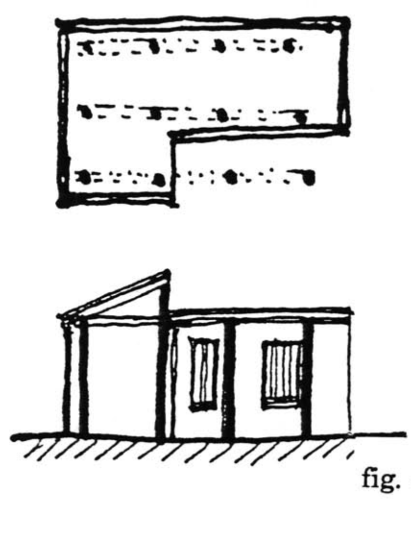


fig. 4-26

reinforce the structural scheme of columns spatially, especially when they are bearing walls. In this section, I shall concentrate on the spatial relation of the Chinese timber-framed system in which the walls are non-bearing enclosure and partitions. Walls as bearing structures will be the subject of the next two sections.

Most Chinese timber-framed halls (fig. 4-27) share the same structural principle and are formed by similar shapes of columns, joints and beam system (fig. 4-28). This shared structural form produces a consistent geometry of spatial layout for columns. These columns are, in general, parallel colonnades positioned in a rectangular structural scheme (fig. 4-29). Within a consistent structural module, there exists a system of coordination among columns, beams and brackets. In a simplified version, the bracket is a transformation of the point of intersection of three elements, columns, primary beams and secondary beams (fig. 4-30). The geometry of the bracket allows a variation of over-hung extensions at various directions (fig. 4-31).

The primary beams run along the short lateral side with the secondary beams running at the longitudinal side. The columns can either extend into the pitched roof in increasing lengths following the slope of the roof or stop at an even height. In the former case, each primary beam is connected with pairs of columns in the lateral direction, instead of penetrating

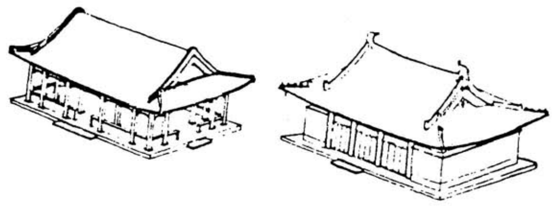


fig. 4-27

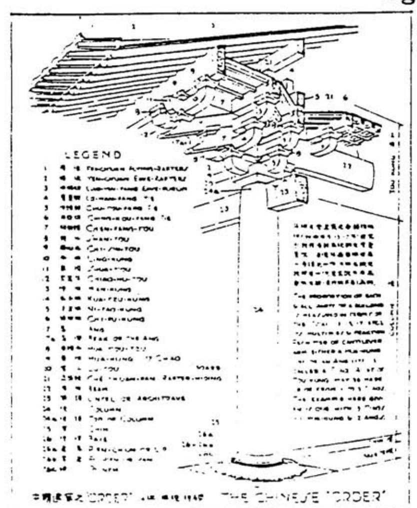


fig. 4-28

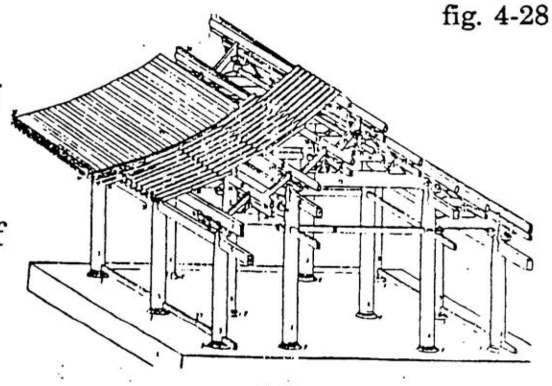


fig. 4-29

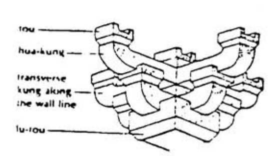


fig. 4-30

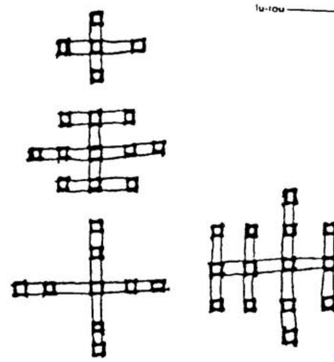


fig. 4-31

through all the lateral columns (fig. 4-32). In the latter case, each primary beam stacks on the lateral columns with shorter beams piling on the long ones following the slope of the pitched roof.

The position of the brackets and the secondary beams are set on a regulated module (fig. 4-33). The positions, numbers, and sizes of columns on these modular dimensions can be varied. The relative dimensions between or among pairs of columns determine the relative sizes of columns and beams.

There exists two types of variations in the structural scheme of the Chinese column system. One type is of one directional variation in which the variations of the dimensions among pairs of columns occur along the lateral direction, with the other direction in consistent distance between the columns (fig. 4-34). The other type is of two directional variations in which the distance between pairs of columns varies at both longitudinal and lateral directions (fig. 4-35).

Most timber-framed halls not only share similar structural forms, but also similar spatial form. This spatial form, in most cases, reinforcing the structural scheme, is of rectangular shape enclosed with an exterior wall. There exists three types of exterior walls: the ceiling to floor wood-screen panels, the wood-screen panels resting on short masonry walls, and the ceiling to floor, non-bearing masonry walls (fig. 4-36). The last, in most cases,

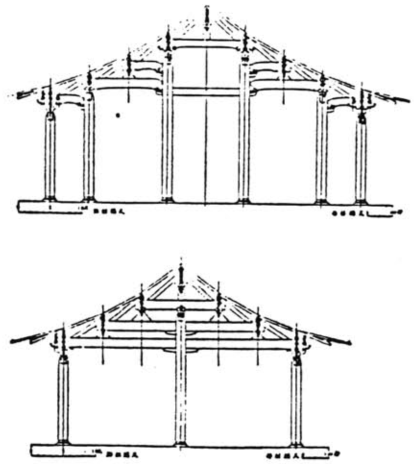


fig. 4-32

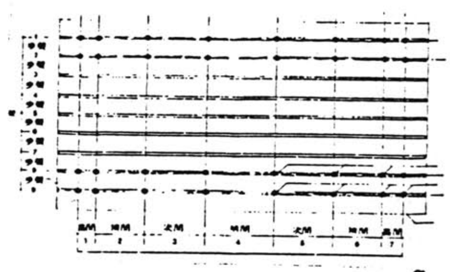


fig. 4-33

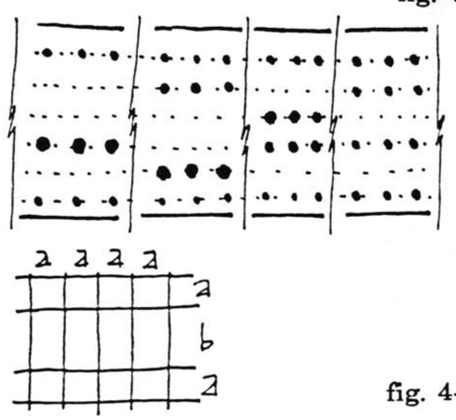


fig. 4-34

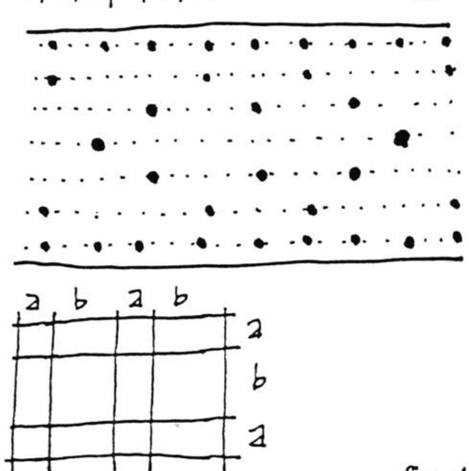


fig. 4-35

embraces the exterior columns. They are self-stabilized, U-shaped containment walls with a widened base. Such non-bearing masonry walls differ from the stucco infill or the wood-screen construction in that it does not necessarily depend on columns to exist. They belong to the wall system that shall be investigated in the next section.

The wood-screen construction is structurally of a lower level than the bearing structural columns. It depends on columns to exist. The wood-screen construction occupies the space between columns. In principle, it demarcates spaces according to the structural module. At the level of the bearing structure, the spatial form is different from that of the level of the screen construction (fig. 4-37). A set of column modular systems provides such physical variations for the structural scheme through the number of columns used and the positional geometry of the columns. At this level, the spatial demarcation is virtually suggested. Each variation of the structural scheme suggests various possible subdivided spaces (fig. 4-38).

In such a way, the spatial form, in a pure column system, responds to the structure at both levels, the bearing level, the variation of the virtual spatial form, and the non-bearing level, the variation of the physical spatial form. The proximity and the regularity of the position among columns in a singular spatial form provide guides of subdivisional geometry and configuration

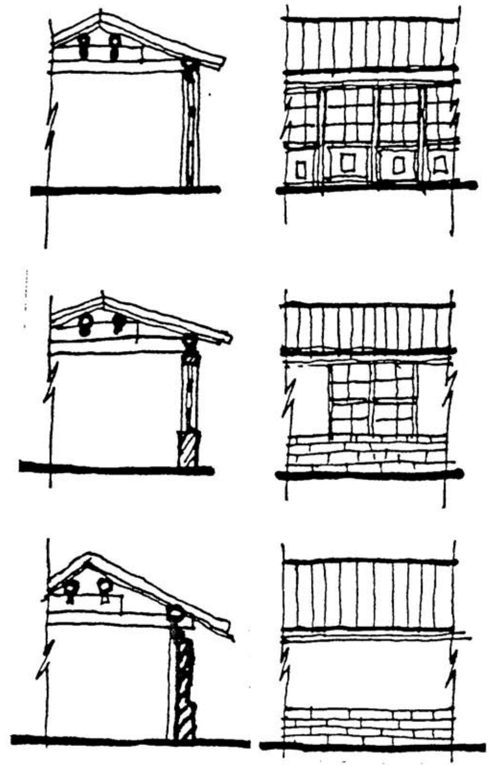


fig. 4-36

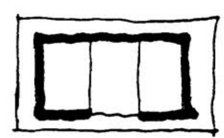


fig. 4-37

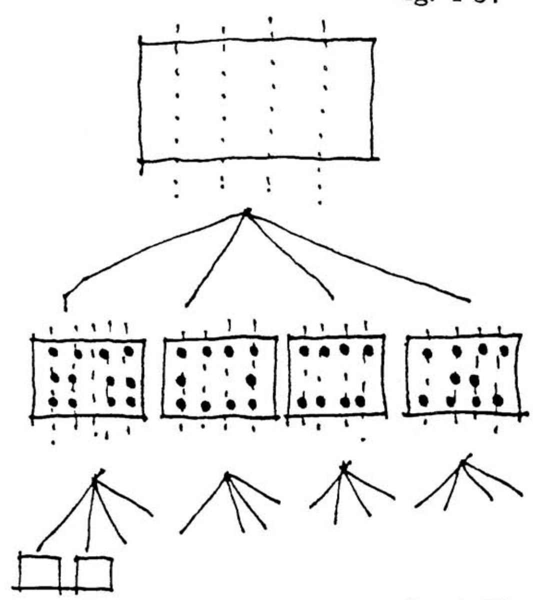


fig. 4-38

for the lower level of structure such as wood-partitions.

The orthogonal singular structural form of a timber-framed hall in conventional Chinese buildings is a unit from which a complex of building forms may develop (fig. 4-39). Two basic types of extension of this unit exist. One is the complex composed of similar units such as a courtyard house (fig. 4-40). The other type of extension of a unit building form is the complex formed through a transformation of the singular unit, such as the vernacular buildings often found in suburban areas liberated from the constraints of a dense urban formal geometry (fig. 4-41).

In the first courtyard type, the individual units are structurally independent from each other. Exterior access, such as the gallery, provides a network of spatial organization for the complex of detached buildings. Axes and symmetries are the formal rules that guide this organizational pattern (fig. 4-42). Often, each rectangular unit consists of a symmetrical differentiation among fronts, sides and backs. A doorway is often located at the front central lines. Correlated geometry and organization are the features that connect the detached structural forms into spatially coherent building forms (fig. 4-43).

In the second type, transformation into complex buildings, each unit or volume is attached to each other through a transformation of the direction, the position,

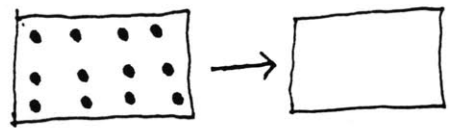


fig. 4-39

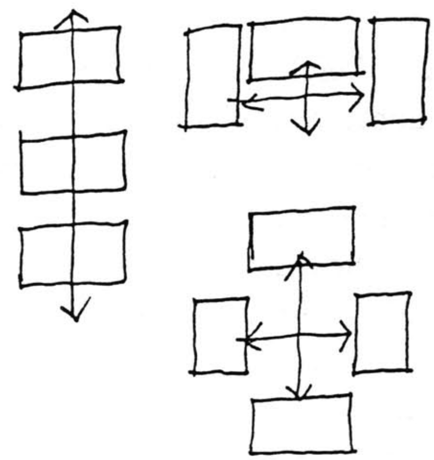


fig. 4-40

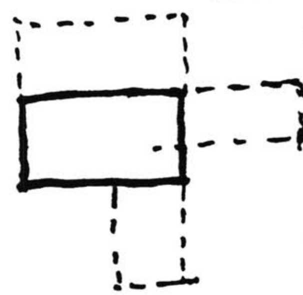


fig. 4-41

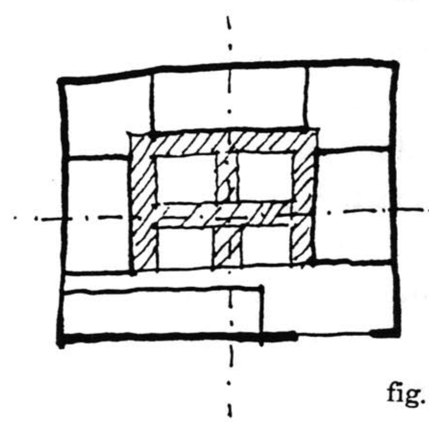


fig. 4-42

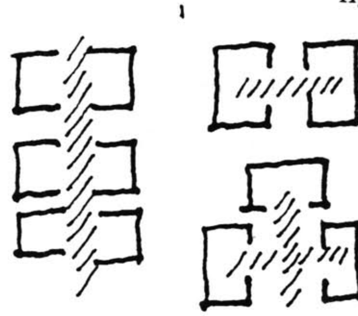


fig. 4-43

and the height of the beams. This complex type is basically free from the spatial rules of symmetry and axes, following rather structural extension in generating enclosed space. Several spatial volumes of varied sizes, height and directions are thus connected through interior openings into a continuous spatial form. Two common types of transformation exist, the L-shaped type, the primary beams of two attached spatial volumes are perpendicular to each other (fig. 4-44); and the parallel type, the primary beams of the attached spatial volumes are parallel to each other (fig. 4-45).

The L-shape type can transform into a courtyard building form of three wings. In this case, the symmetry provides the guide for the spatial layout (fig. 4-46). In the parallel transformation type, parallel primary beams of the same height may generate one continuous hall in which individual unit of space merges into a singular spatial form (fig. 4-47). Here, it is the additive growth of units of space as opposed to the implied subdivisional space in one singular spatial form (fig. 4-48).

The exterior boundary of a timber-framed structural system defines a singular three-dimensional volume. The definition can be either physical or virtual. The latter case applies to a pavilion where all the perimeter columns are exposed (fig. 4-49). The former applies to the case when ceiling to floor masonry walls enclose all the exterior boundary (fig. 4-50). There the walls play a

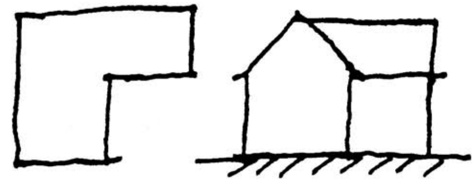


fig. 4-44

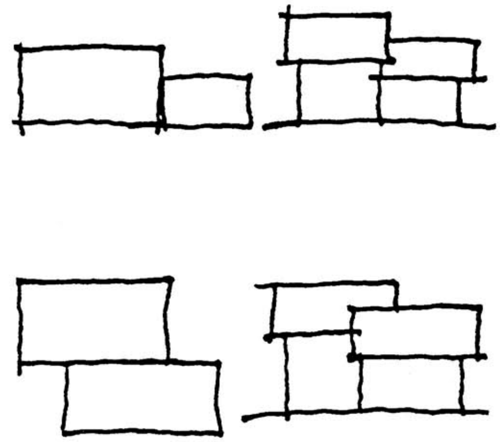
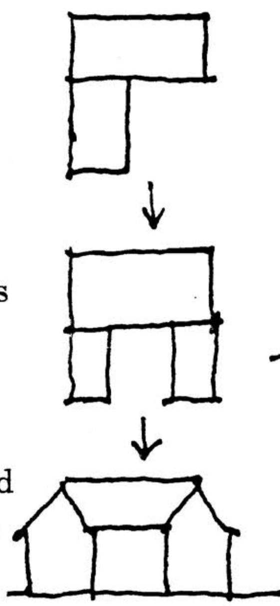


fig. 4-45



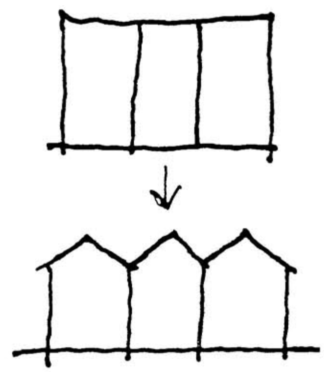


fig. 4-47

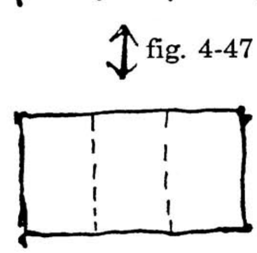


fig. 4-46

fig. 4-48

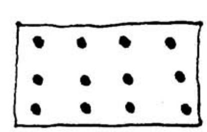


fig. 4-49

spatial role that reinforces the spatial intention of the skeletal column structure. In other words, a non-bearing structure cooperates with the bearing structure in realizing one spatial form.

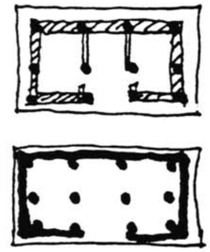


fig. 4-50

The Wall System

In conventional masonry buildings of both Western and Far Eastern traditions, we may distinguish two types of masonry walls, bearing and non-bearing. The non-bearing walls serve mainly as self-supporting space-enclosures, while the bearing walls can be both supports and enclosures, with support playing the dominant role, thus influencing the degree of space enclosure.

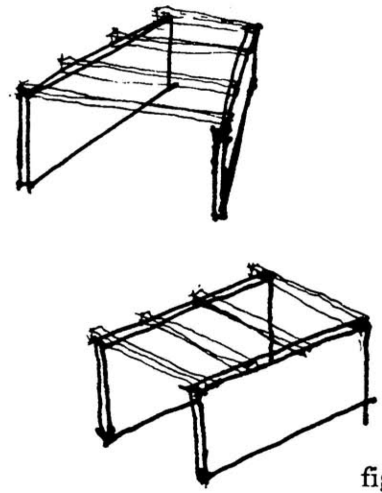


fig. 4-51

Ususally, in a pure wall system, we need at least two sections of wall-planes parallel or at an angle, in order to generate a roofed space (fig. 4-51). Normally, parallel walls are adopted. One reason for this choice is that uniform lengths of beams are more economical, as there is a maximum span for any beam and beams must be increasingly deep and more strongly supported the greater the span (fig. 4-52). Most often, beams span in the shorter direction, lying directly on the walls.

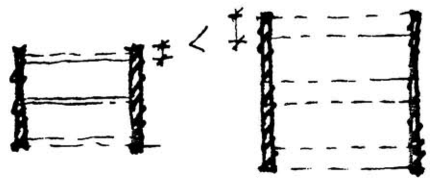


fig. 4-52

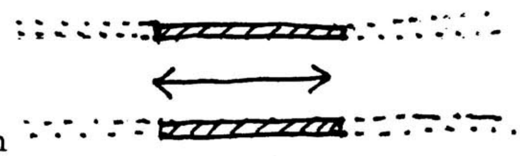


fig. 4-53

The parallel structural wall scheme privileges growth in the longitudinal direction (fig. 4-53). This structural scheme generates the row house building type.

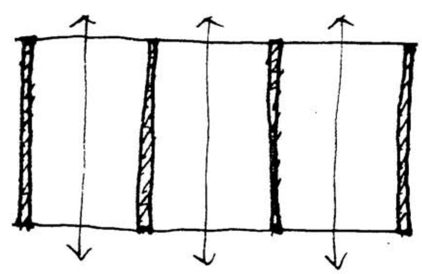


fig. 4-55

In the row house type, the urban building typology limits the major access of the elongated house form to the narrow side of the house. Also, the bearing role of the longitudinal walls allows the narrow side freedom of openings (fig. 4-55). The circulation, including staircases, usually occurs at one side of the elongated plan, rather than at the central axis. This allows, within a narrowly confined lateral space, adequate

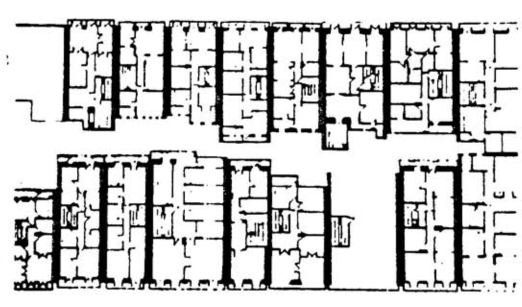


fig. 4-56

habitable dimensions at the other side. The internal walls perpendicular to the parallel boundary walls are usually non-bearing walls (fig. 4-56).

Spatially, the parallel walls define an elongated spatial procession, instead of a containment. They are "planes" which either suggest lateral direction along the walls, or project a territory depending on the length and the distance between the two supporting planes. The longer the planes or the narrower the space between the two planes, the stronger the suggestion of a directional movement (fig. 4-57). As the distance between the planes becomes wider, the direction between the two planes may become more prominent than the procession along the walls (fig. 4-58). If the planes are less extended, the spatial form retreats from a procession to a virtual domain (fig. 4-59). Piers, if laterally extended or closely spaced, perform like narrow wall planes which suggest a virtual lateral movement, while generating a radial zone around them. A pair of narrow wall planes closely spaced form a transient passageway or gate (fig. 4-60).

Walls as planes demand more than a singular section in order to support the roof and to stabilize themselves. As these planes connect into L, U or box-shaped enclosures, they tend increasingly toward spatial containment. In these cases, the walls are usually self-stabilized and can be either bearing or non-bearing elements (fig. 4-61).

The L-shaped walls form a corner condition. The corner space defines a triangular spatial

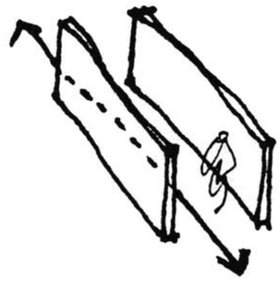


fig. 4-57

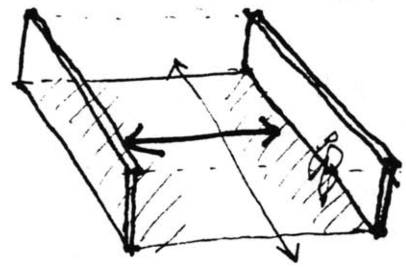


fig. 4-58

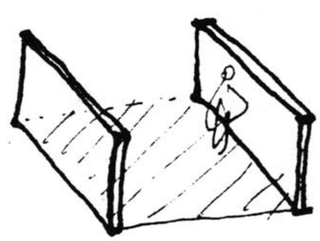


fig. 4-59

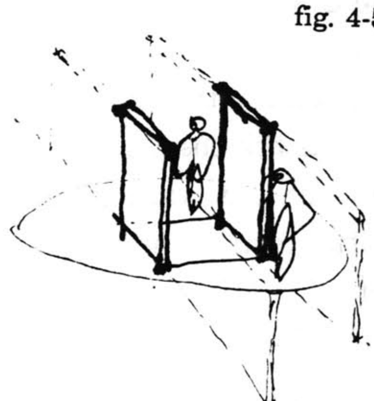


fig. 4-60

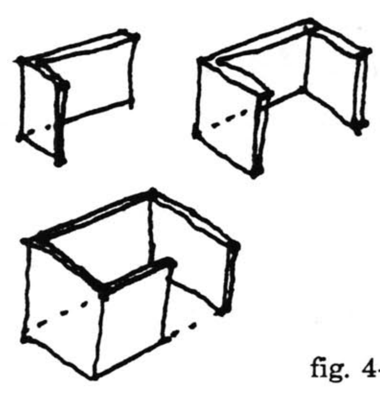


fig. 4-61

form while suggesting an orthogonal extension of virtual spatial forms which override the physical definition of the corner condition. As a spatial form, it is considered a partial containment; as a structural form, it is a singular virtual structural element that demands extra supports such as another wall plane, column or anchors in the walls in order to break away from the triangular form (fig. 4-62). (In modern materials, such as space frames or reinforced concretes, the L-shaped structural form may easily break away from the triangular spatial form.)

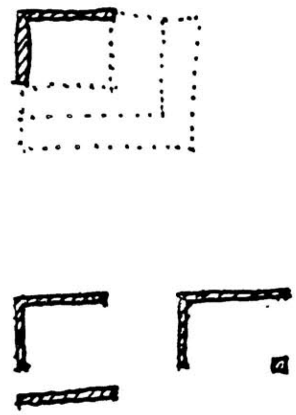


fig. 4-62

The L-shaped walls are important structure-versus-space constituents of the box-shaped masonry buildings (fig. 4-63). The wall system as both containment and self-sufficient structural form occur with the U-shaped walls. The U-shaped walls that bound three sides of a space can be supports as long as the distance between the two parallel sections does not exceede the possible span of the beams. These containment walls present dominant physical spatial forms which constrain the possible virtual spatial form, if it must be contained under the roof supported by these walls (fig. 4-64).

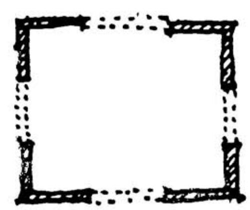


fig. 4-63

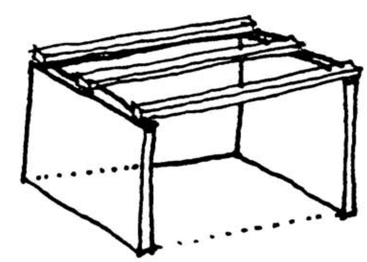
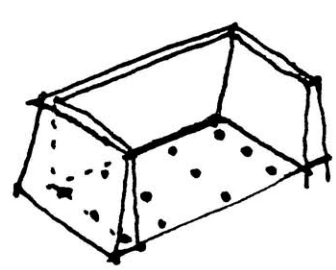


fig. 4-64

The U shaped enclosure presents a distinct differentiation between the opening side at the front, and the enclosed side at the back. Chinese timber framed halls adopt this wall as an enclosure since it complies to the symmetrical organization among a group of building units (see discussion on columns earlier in this chapter) in which the front and the back of a building are both important



symbolic and physical devices for spatial orientation (fig. 4-65).

The elongation of either directional wall in the U shaped containment-walls generates different spatial typology which may demand extra structural support, such as columns in Greek stoa or some megaron temples. This leads to column and wall system, which shall be discussed later in this chapter.

The box-shaped spatial form with an addition of a fourth wall is a further transformation from the U-shaped spatial form. Greek megaron houses and temples are typical examples (fig. 4-66). In these cases, beams lie on two planar walls of the long sides, similar to the parallel wall system. Often extra column supports are added along the elongated sides.

Complex masonry building typology often adopt the box-wall system. In these building cases, walls as containments are usually combined with walls which function as non-bearing planes.

In a Greco-Roman courtyard house complex, each unit of the building complex is often of rectangular shape. This elongated spatial form is subdivided into smaller internal volumes by internal walls, with exterior access at the elongated side. These internal walls can be either bearing or non-bearing walls (fig. 4-67).

The non-bearing internal walls are often placed perpendicular to the bearing walls, structurally strengthening the bearing walls, while spatially enclosing and subdividing the structural containment formed by the bearing walls (fig. 4-68).

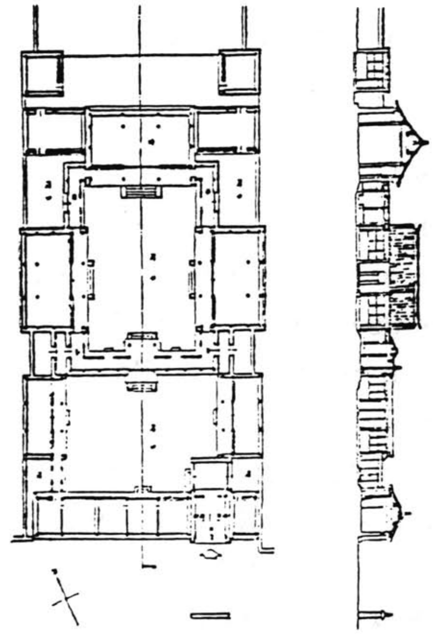


fig. 4-65

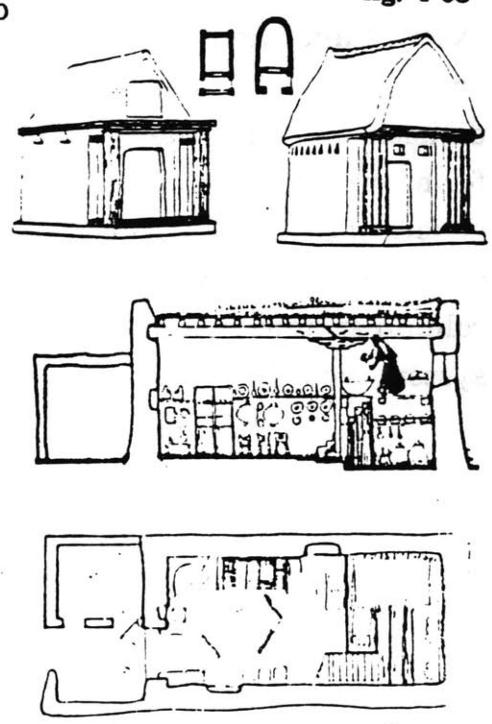


fig. 4-66

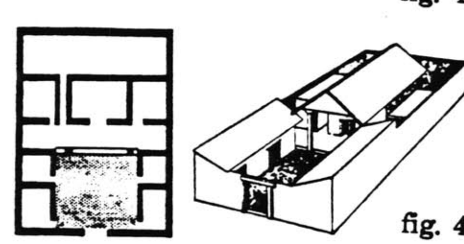


fig. 4-67

dividing the structural containment formed by the bearing walls (fig. 4-68).

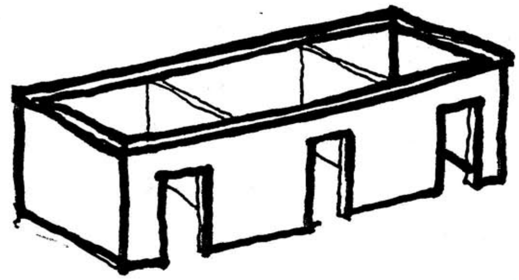


fig. 4-68

When internal walls are bearing walls, the dimensions between the elongated parallel walls can be widened and the primary beams may run along the short side of the rectangular enclosure (fig. 4-69). The use of internal walls as both bearing and non-bearing walls generates various complex spatial types, most distinguishable in institutional buildings or large mansions, such as is found in Palladio's designs, which follow the classical masonry convention (fig. 4-70).

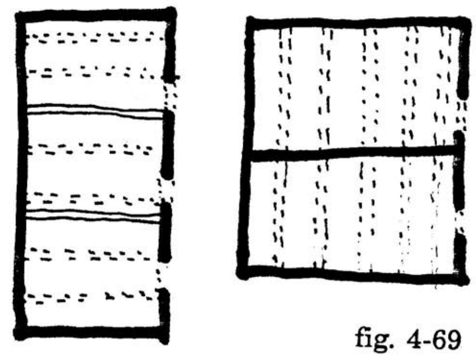
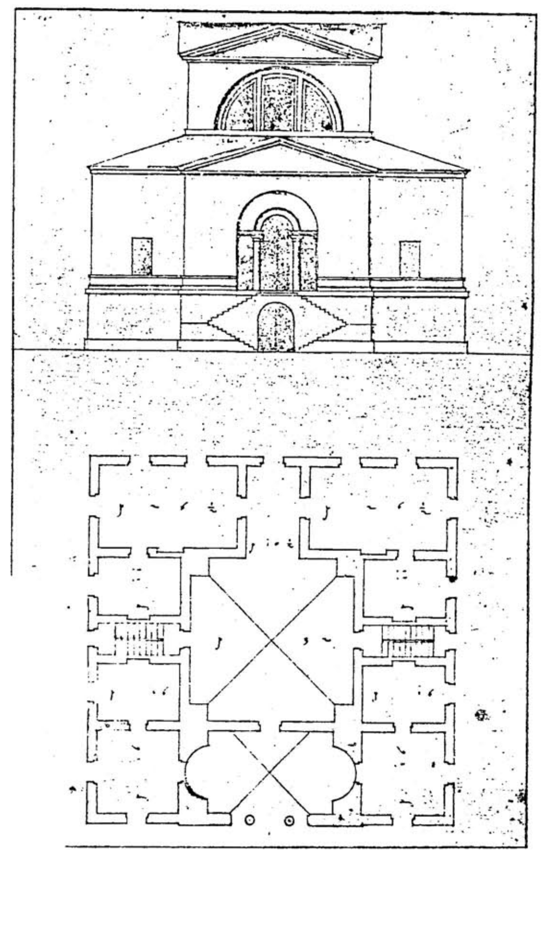


fig. 4-69

In box-shaped masonry buildings, the exterior and interior walls, either bearing or non-bearing, demarcade clear spatial division in which the structural and spatial form coincide with one another in generating sub-divided cell spaces. Such a spatial phenomenon differs from what the column system or even a more open wall system would convey.

fig. 4-70



Column and Wall System

When both structural columns and walls are used in a building, there occur two types of structural schemes. In one type, primary beams span on either columns or walls at separate structural lines (fig. 4-71); at the other type, primary beams span between columns and walls on the same structural line (fig. 4-72). In the latter, the columns and beams substitute for sections of walls as a continuity of the main support system.

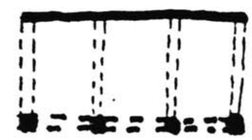


fig. 4-71

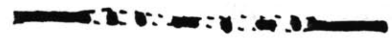


fig. 4-72

Columns and Walls on Separate Structural Lines

In this type of column and wall structure, the wall encloses a physical spatial volume, while the separate column structure defines a virtual spatial volume. The two overlap with each other, forming layers of spatial forms. There are three possible conditons in this category of column and wall relationship: Walls enclosing columns in the interior, such as a hypostyle mosque (fig. 4-73); columns surrounding walls, such as Greek temples (fig. 4-74); or, in a combined version of the first and the second, columns occuring at both the interior and exterior of the walls (fig. 4-75).

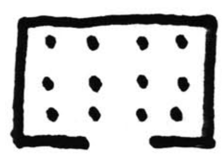


fig. 4-73

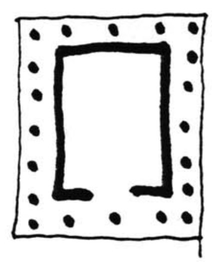


fig. 4-74

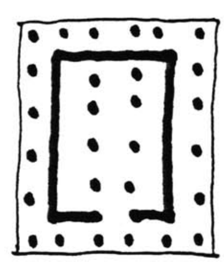


fig. 4-75

Walls in early mosque types appear mostly around the perimeter. They enclose a single spatial volume. Within this spatial volume, there are smaller virtual spaces suggested by the colonnades. Differing from the Chinese column system which allows a variation of the spatial position of columns at the primary structural level, the column system of a mosque relates to space in rigid modules. Four adjacent columns form a smallest unit of virtual modular space that is constantly and often consistently repeated.

Differentiation of this rigid modular structural form is made through an expansion of the dimensions of certain colonnades so that some domains can be distinguished from the others (fig. 4-76). At a later development of mosque form, the mihrab and the central processional axes topped with domes and arched roofs, often are supported by columns of shapes and scales different from those of the other areas (fig. 4-77). Here, the variations of the shapes and dimensions of the structural form in defining spatial volume generate various virtual subdivision of spatial forms (fig. 4-78). Structually, there remains one level of primary support system, the modulated colonnade. This one level of primary structure, however, shapes a varied hierarchy of spatial domains. This hierarchy of structural and spatial relationships is different from the Chinese timber-framed hall in which the hierarchy of spatial forms depends on the positional variations of columns and the introduction of a hierarchy of structural members.

The hypostyle mosque is a case in which the column structure is predominant, the walls mainly serve to enclose the space and, secondarily, to provide support for the perimeter beams. In contrast, early Greek megarons or temples are cases where walls are

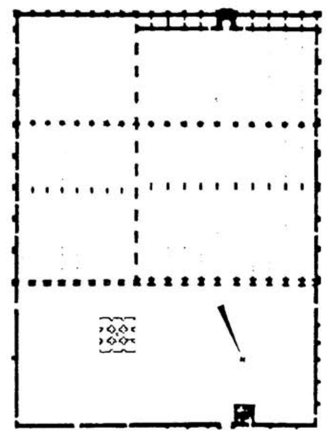


fig. 4-76

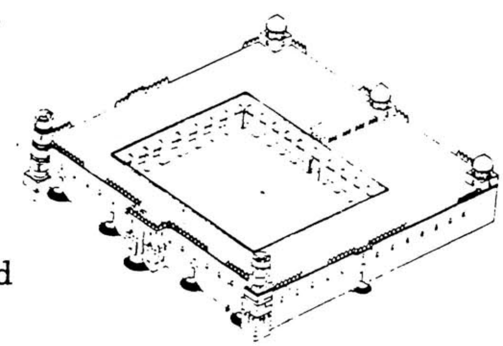


fig. 4-77

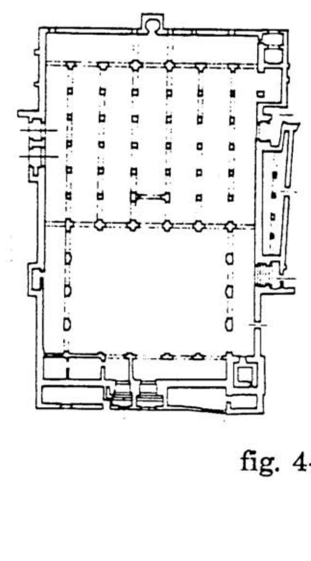


fig. 4-78

the predominant structure and the interior columns (fig. 4-79), when they occur, supplement walls in supporting the roof (fig. 4-80).

We now come to the case where columns complement walls in generating spaces. These columns may be at the exterior of the wall enclosed space or the interior. In the case of Greek temples, the structural relation of the columns to the walls is a development from a supplementary support to an equivalently meaningful structural and spatial role with the walls. The colonnade and the walls work together as a coherent structural form in generating spatial forms (fig. 4-81).

The exterior colonnade around the perimeter of the wall defines both an integral spatial volume under the roof and a virtual volume between the wall and colonnade (fig. 4-82). Columns and walls as one coherent structural form generate two layers of spatial volumes. These layers of spatial volumes merge with each other formally more than they are differentiated from each other.

We can find various typologies of how an exterior colonnade space relates to the wall enclosed space. For example, the colonnade may parallel the wall construction at one, two, three or four sides (fig. 4-83). Each suggests a varied connection of the walled interior relating to the exterior. These exterior colonnade typologies have two possible directions of spatial movements. One is perpendicular to the walls and associated with the access to the wall enclosed space, and the other is parallel to the walls and related to the

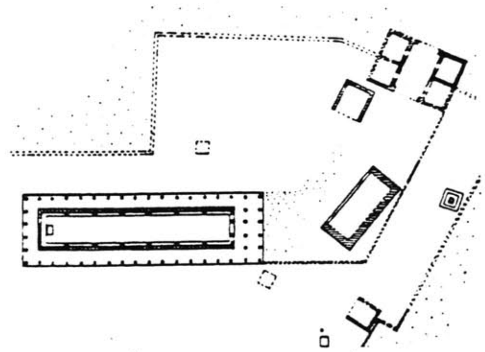


fig. 4-79

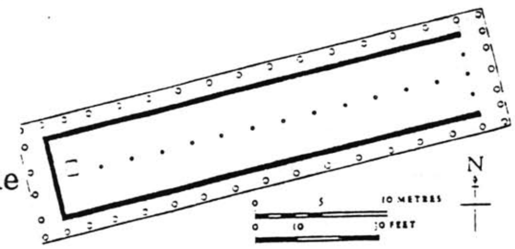
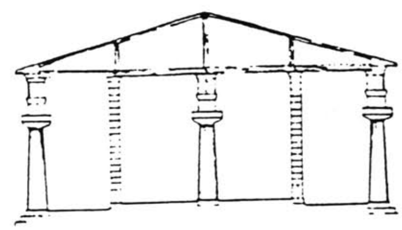


fig. 4-80



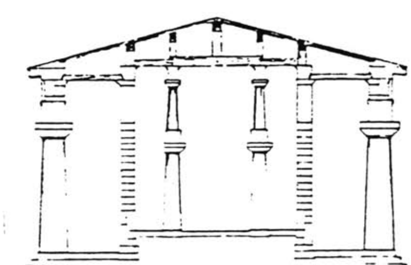
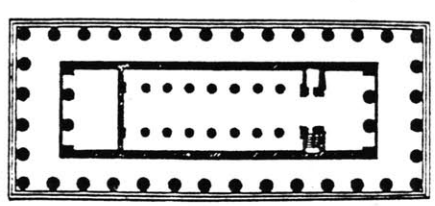


fig. 4-81

fig. 4-82



promenade along the exterior colonnade (fig. 4-84).

When colonnades appear at both the interior and exterior of a wall enclosure, at least three levels of hierarchy of spatial forms exist. The dominant level is the wall enclosed space, the second level is the virtually defined colonnade space, the lowest level is the volume between the columns and the walls. These three levels overlap with each other, generating various possible spatial demarcations (fig. 4-85).

Colonnades occuring at both the interior and exterior in symmetrical structural and spatial relationship with the walls are found in classical buildings. The symmetry reinforces the continuity between the wall defined space and the column defined space, forming one dominant coherent spatial form with correlated subdivisional spatial forms at lower levels.

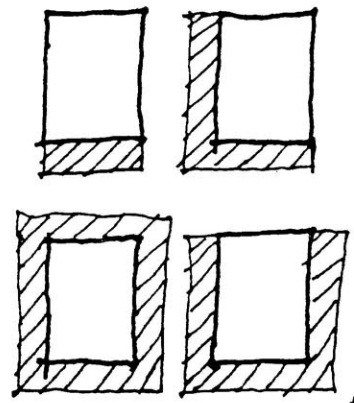


fig. 4-83

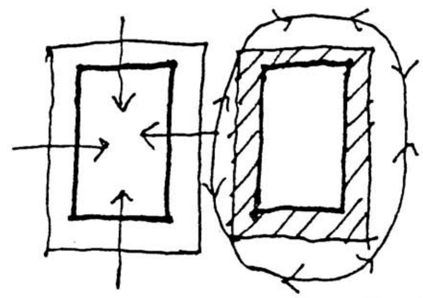


fig. 4-84

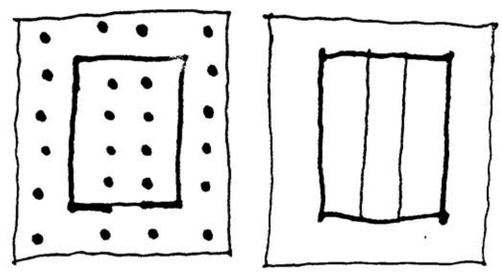


fig. 4-85

Columns and Walls on the Same Structural Line

Walls and columns on same structural lines may form cave-like enclosures. However, they may also form open structures more like colonnaded space (fig. 4-86). The spatial definition of this wall plus colonnade extension depends on the ratio of the walls and columns used.

The hierarchical relationship between columns and walls as structural forms is important in this system in affecting the

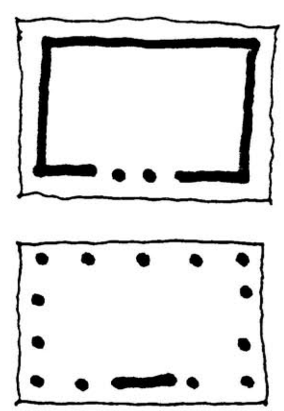


fig. 4-86

complexity of the spatial forms. Two conditions exist: either both columns and walls as primary bearing elements or they are the bearing elements at different structural levels (fig. 4-87).

When columns and walls are bearing elements of the same hierarchical levels, they are parallel supports for floors and roofs and relate to the same spatial form thus confined.

Both orthogonal and round columns are possible in conjunction with the walls. Orthogonal columns may or may not demand a capital, while with the round columns, a capital as transition between the round surface of the columns and that of the beams is preferred. There exists two possible ways the round columns in conjunction with the walls. In one, columns and walls are found in trabeated form, in which the columns assert spatial zone around it as differentiating from that of the walls (fig. 4-88). In the other way, columns and walls form arched openings. This can be illustrated by a transformation from narrow wall supported arches to the round column supported arches (fig. 4-89). In such a structural form, the continuity of the wall in defining space dominates over that of the columns. The round column supported arches often demand the addition of joints between the lateral wall extension at the top of the round columns.

There are also cases when columns and walls overlap with each other as a redundant structure, typical in Renaissance buildings. In this case, columns and walls form a single-

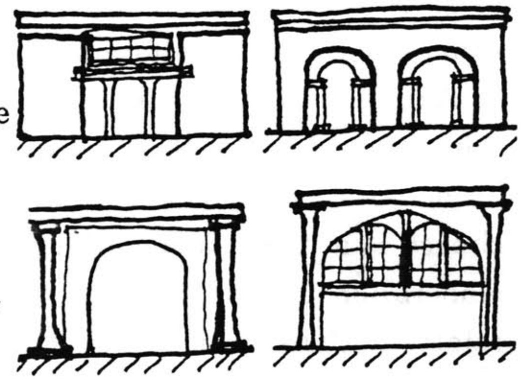


fig. 4-87

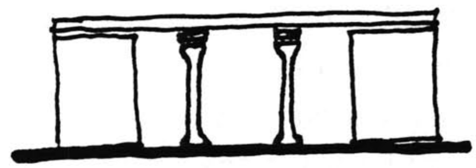


fig. 4-88

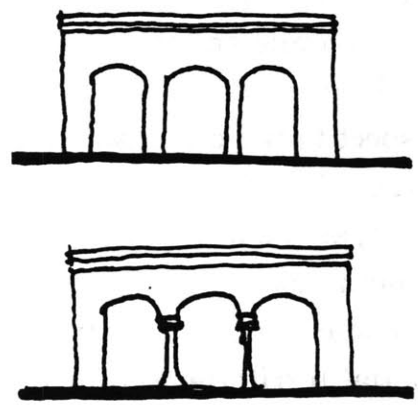


fig. 4-89

fig. 4-90

mass structure, even though the columns are shaped as bearing columns (fig. 4-90).

A hierarchy of spatial form is possible with columns and walls at different structural levels. For example, the facade of Gothic church is a case when columns in sculptural elaboration are the primary structure that relates to the spatial volume of the church hall; while the walls with openings are a secondary structure which define the space of the window frame (fig. 4-91). The colonnade arcade of the Basilica in Vicenza also shares the similar structural hierarchy in which the larger columns merge with pier walls to confine the arcade; while the wall infills and the smaller columns between the primary columns define the arched openings (fig. 4-92).

Columns and walls of different hierarchical level differentiate varied spatial forms with respect to the dimensional scale. Usually, the larger size of structures, either columns or walls, as the primary structure relate to the building as a whole, while the smaller sizes of secondary or tertiary structures delineate the spatial territories confined within or can be differentiated from that of the primary structure. A sequential layers of spatial territories unfold as we approach such a structural form from the whole to the parts.

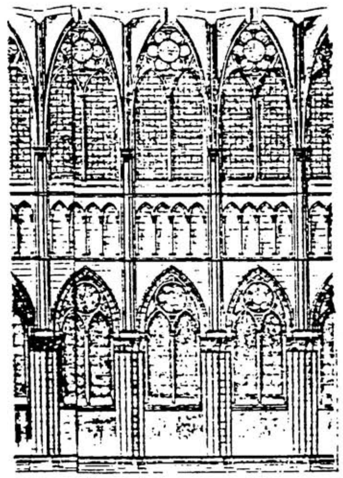


fig. 4-91

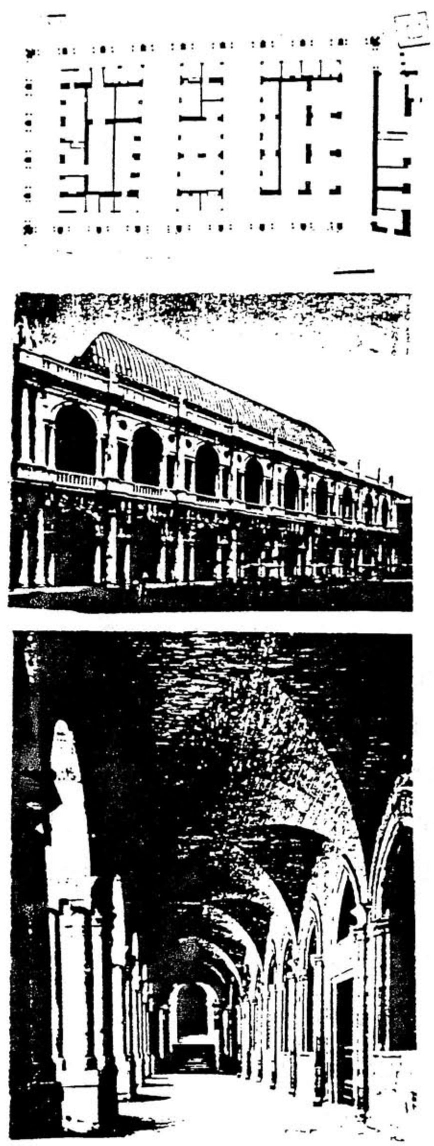


fig. 4-92

Chapter Five

THE THREE CASES

Case One

Carpenter Center

The Walls and the Physical Spatial Form

The building with the deep recess at the ground floor, appears to be elevated from the ground level, and begins to be articulated formally from the second level onwards. Above the ground floor, the building is a confluence of six differentiated spatial volumes contained by exterior walls (5-1-1).

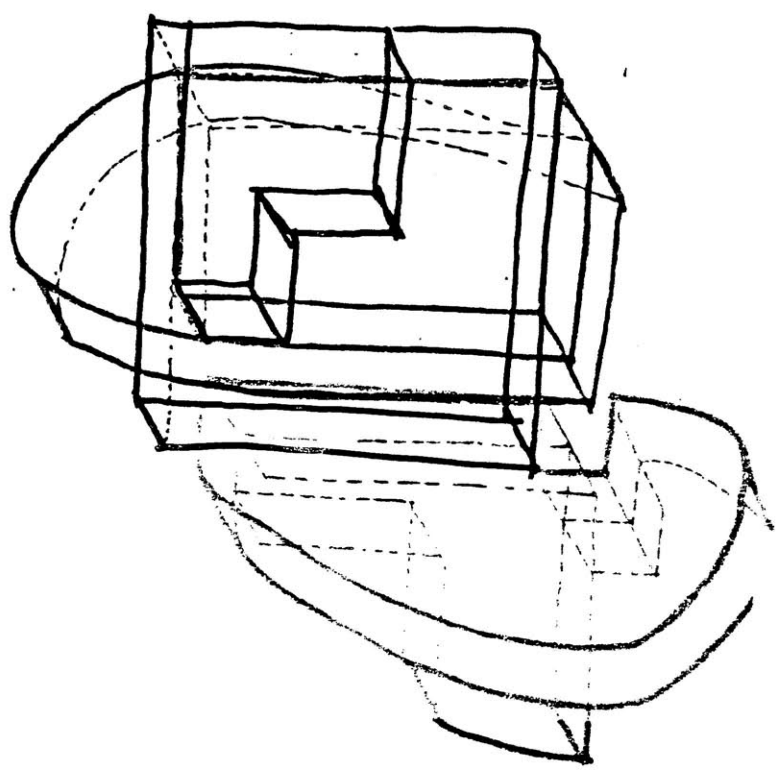


fig. 5-1-1

Each of these spatial volumes has a different geometric shape. The orthogonal and ovoid spatial volumes are in some places, tangential to one another through the continuity of wall surfaces (fig. 5-1-2).

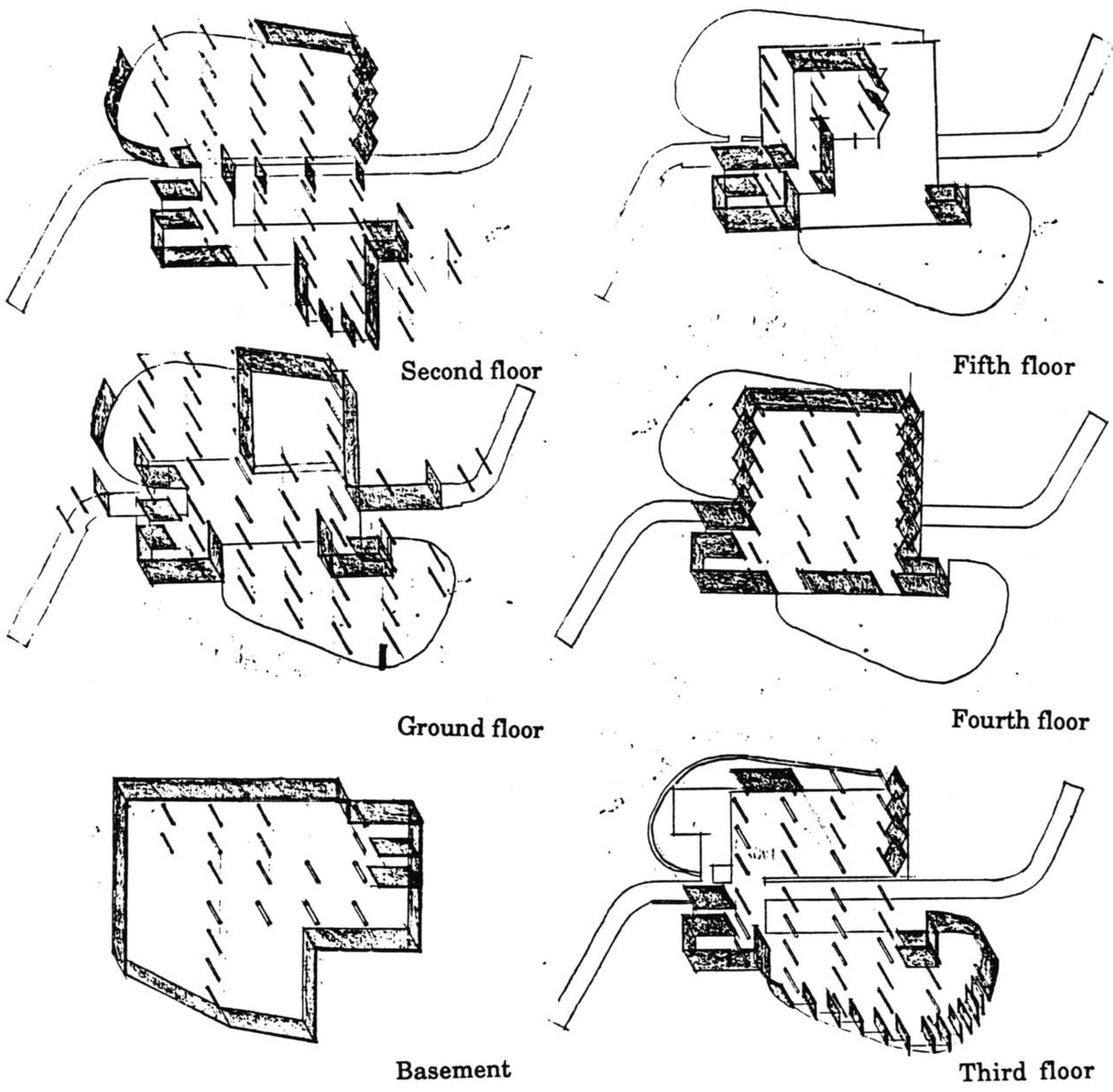

Second floor
Fifth floor
Ground floor
Fourth floor
Basement
Third floor

fig. 5-1-2

The ovoid volumes form the two central spatial volumes of the building, one at the south side, the other at the north side, occupying the second and the third floors. The orthogonal spatial forms at the fourth and the fifth levels cover the central zone of the ovoid volumes and overlap with them at the north-east edge, acting as a joint. The enclosed spatial form at the basement and the ground level, different from those at the top levles, does not present a distinct geometry.

The two basic spatial geometries, ovoid and orthogonal, at the second, third and fourth floors enclose the column clusters. This wall-enclosed-column spatial typology approximates the type of the hypostyle mosque, though, structurally, the walls do not generally take the load. We may think of it as a combination of both walls as structure and as non-bearing enclosure.

These concrete walls can be differentiated into four categories: the two types of bearing walls, the non-bearing walls, and the sun-baffles. There exist two types of bearing walls. One forms the support for the main stairwell at the south-west corner. The other appears at two locations, one being a pier, at the south-east corner, forming a formal continuity of the sun baffle from the second floor; the other at the north-west corner is also a continuity of the exterior enclosure from the second floor (fig. 5-1-3).

These two conditions of bearing walls address two different structural and spatial schemes, while sharing the same structural principle in supporting the concrete slabs. In one condition, the stairwell forms a pure wall enclosure by itself independent of the column system. In the other condition, the bearing walls cooperate with columns in supporting the concrete slabs resembling a column-wall structure. In the latter case, however, the indifferent geometric relation between walls and column modules spatially dissociates the bearing walls from the column scheme.

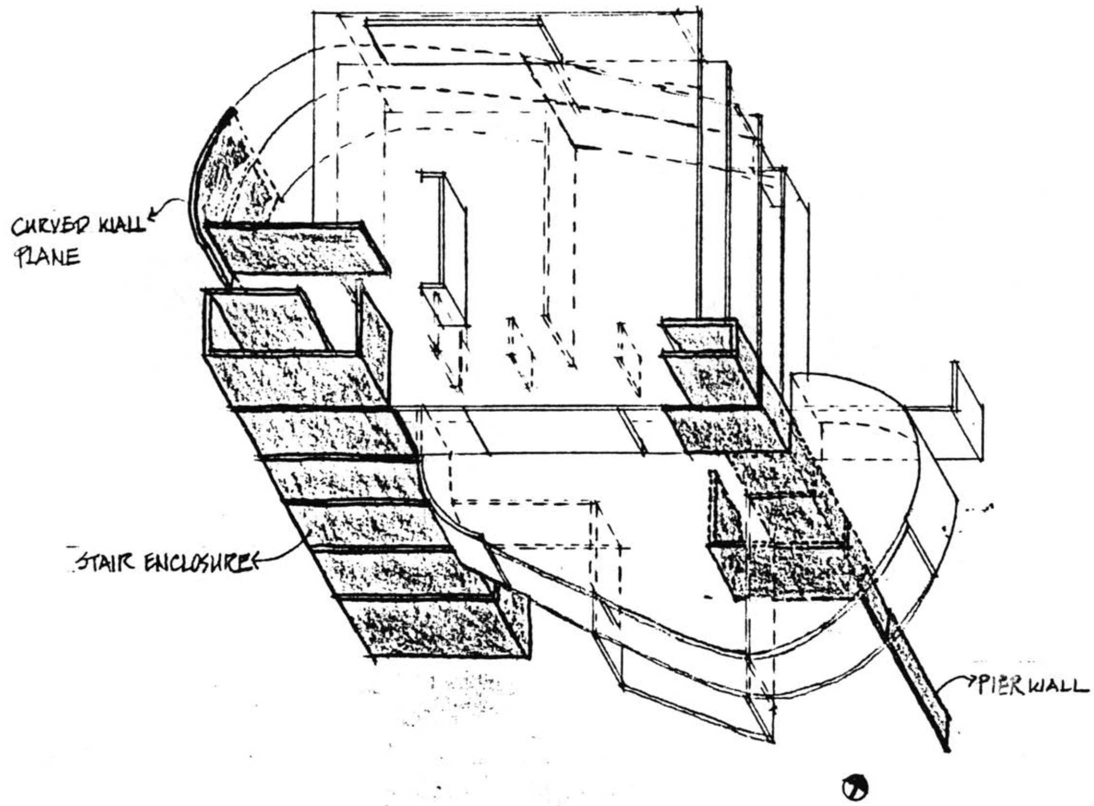


fig. 5-1-3

Visually, the bearing walls are related more to the non-bearing enclosure as they conform to the shape of the non-bearing enclosure and, at the upper floors, merge with the non-bearing enclosure which they themselves support. These bearing walls do not conform to the structural scheme as a whole, but rather are projections of the spatial form from the upper level to the ground floor. They are a stronger presentation of the vertical formal continuity than what is conveyed by the virtual form of the column scheme (fig. 5-1-4).

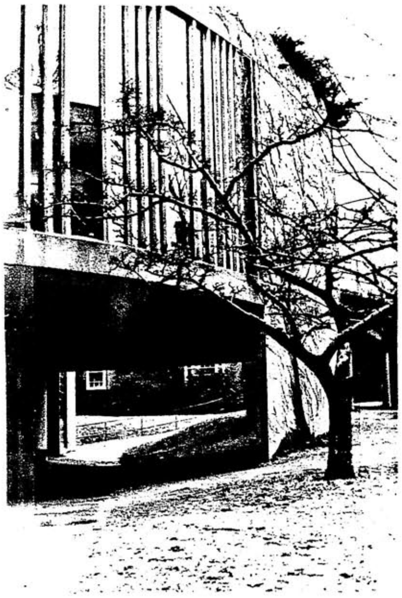


fig. 5-1-4

The curved bearing walls at the north-west corner still suggest a virtual spatial volume which is related to the physical spatial geometry at the second floor, while the singular pier at the south-east corner, sharing the same object quality as its neighboring columns, does not suggest any spatial demarcation.

The non-bearing enclosure is the main element that forms the physical spatial form of the building. These enclosures, in general, are exterior walls. Only at the basement and the theater space which occupies part of the basement and the ground floor do concrete walls provide a continuous boundary for the enclosed spaces. Above the ground floor, the perimeter walls, though they run continuously throughout a single volume, change at intervals into different materials, dimensions or positional geometries. There are basically four elements together forming the physical enclosure, the concrete walls, the sun-baffles, the concrete struts and the glass (fig. 5-1-5).

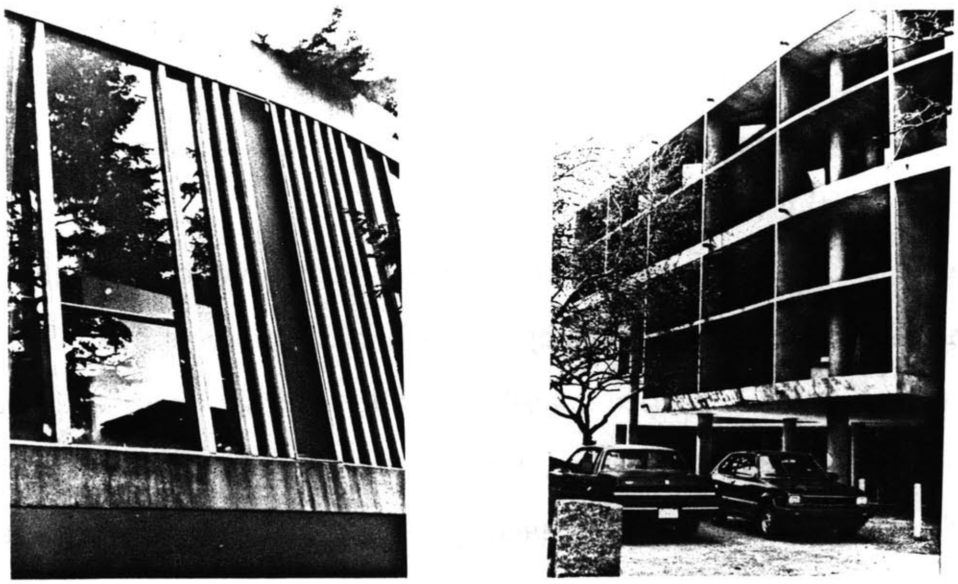
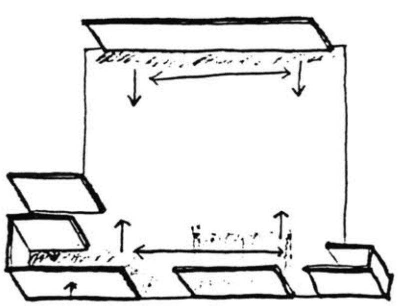


fig. 5-1-5

The concrete plane walls and containment walls appear in two patterns of space enclosing. In one pattern, they form in curvilinear shape, in the other pattern, they are straight planes which either occupy continuously one side of an enclosed space, or are short discontinued planes with openings between each other. The curvilinear section of walls physically contains a partial domain, while the straight section of planes projects territories which, if beyond a certain length, stress the linear extension, or if within certain length, define a domain (fig. 5-1-6).



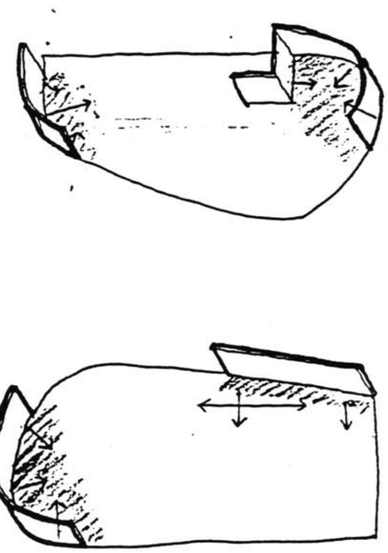


fig. 5-1-6

The sun-baffles further break up the continuous wall plane. With either 60 or 90 degrees difference from the normal boundary wall surface, these sun-baffles form virtually a continous wall plane with glass panels hidden from the continuity of the concrete surface.

Three spatial patterns are generated at this boundary zone: the directional movement along the angles of the openings, which connects interior and exterior, the contained "portico-space" partially enclosed from the direction perpendicular to the boundary line, and the directional movement parallel to the boundary zone which connects each "portico space". These three patterns in forming a continuous facade generates a dynamic spatial zone different from the static planar walls with which these facades connect (fig. 5-1-7).

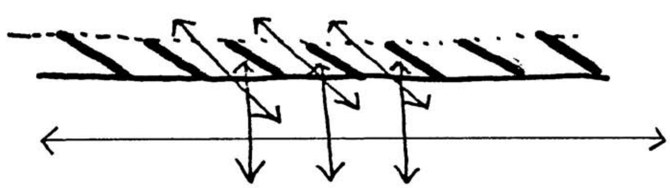


fig. 5-1-7

The introduction of a portico-boundary zone softens the edge of the planar walls. This soft quality is enhanced by the fact that most sun-baffle panels are sandwiched between two slabs, and do not act as structural supports. From the interior, the sun-baffles relate to rows of columns in their repetitive rhythm. The colonnades that are adjacent to these sun-baffles tend to merge with the spatial form of the sun-baffles into one coherent form, discontinuous from the rest of the columns (fig. 5-1-8).

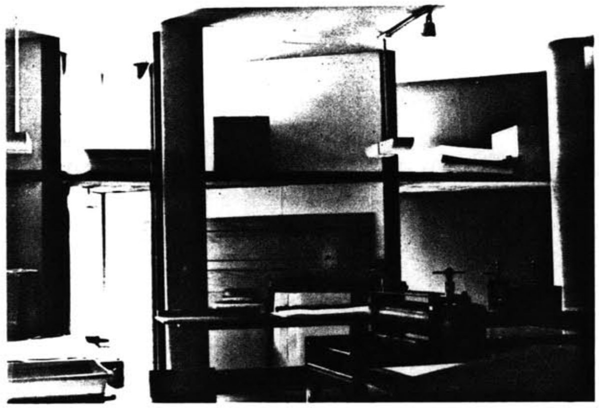


fig. 5-1-8

The thin concrete window struts are elements that demarcate the planar openings. There are two configuration patterns of these struts. In one pattern, pairs of struts form a frame, supporting pivoting wooden doors. In the other pattern, the concrete struts, framing glass, are placed at irregular intervals. The latter occurs at the curved side of the oval volume at the second floor.

Differing from the sun-baffles, which are sections of the planar walls, the window struts are vertical linear elements that tend toward a growth to planar walls. The curved strips of struts at the second floor materialize this tendency, with the struts moving between loose intervals at the gentle curve to tight intervals at the turn of the sharp curve, and eventually merging with the continuous wall plane.

The concrete planar walls, the sun-baffles and the window struts form one dominant singular spatial volume within which each type of enclosure contains or projects subordinate territories. As a result, the singular spatial volume is demarcated into varied virtual spatial domains through these varied types of enclosures. Such a perimeter enclosure pattern draws attention to the locality within a singular open space, weakening the presence of the colonnades as dominant form-givers in space. The resulting spatial phenomenon is quite different from the hypostyle mosque in which the continuity of the wall texture throughout the perimeter lends to a prominent reading of the virtual spatial form of the rows of columns. The columns become regular repetitive units serving for orientation within the varied spaces shaped by the perimeter elements.

The Columns and the Virtual Spatial Form

At the Carpenter Center, cylindrical reinforced concrete columns are the main structural supports for concrete slabs which form both floors and roofs. At the ground floor, these columns are three diameters, 1'-10", 1'-6", and 1'- 4". The 1'-10" and 1'-6" columns begin either from the basement or from the ground, while the 1'- 4" ones start only from the ground. The three sizes of columns are distributed in such a way that the 1'-10" ones are located around the center and support five floors of concrete slabs, the 1'-6" ones are adjacent to the center and support four floors of concrete slabs and the 1'- 4" ones are around the perimeter and support three floors. These dimensions reduce sequentially as they rise into the upper floors (fig. 5-1-9).

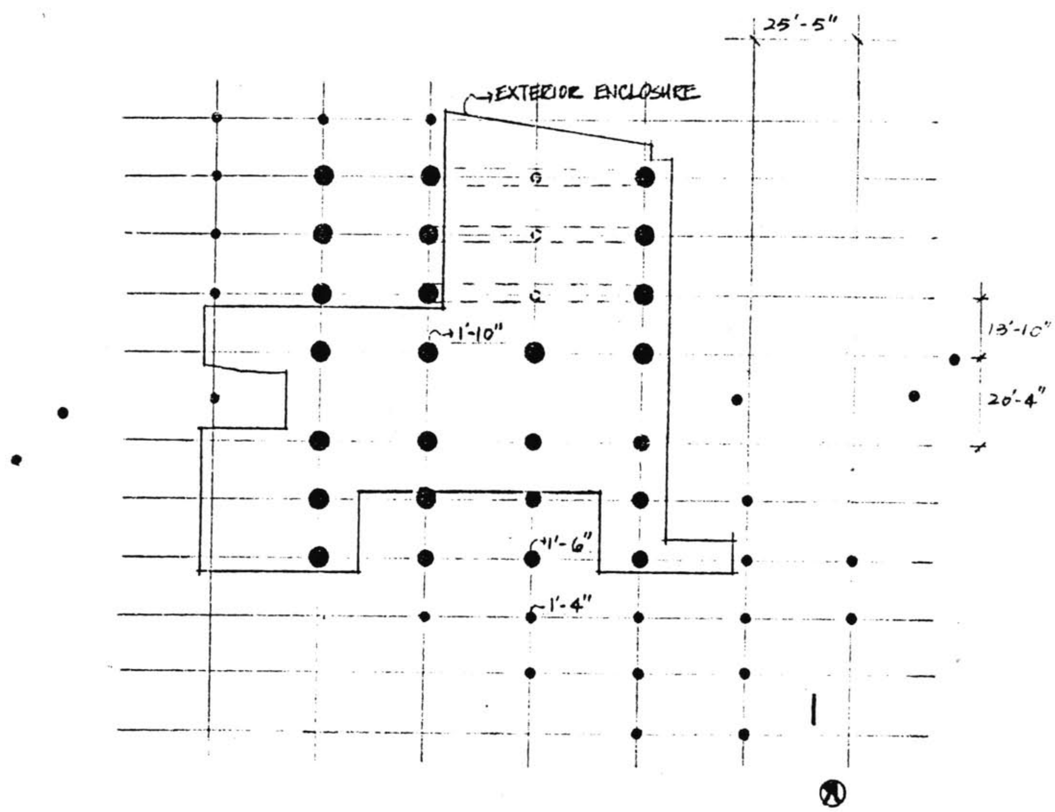


fig. 5-1-9

The structural scheme of this concrete column-slab system is composed of rectangular modular units of 13'-10" x 25'-5", with one exception at the central east-west axis containing the central ramp, the bay dimension of which is 20'-4" x 25'-5". The extended geometry consists of a regular pattern near the central axis and an irregular pattern at the perimeter. The irregularity is induced by the non-orthogonal spatial geometry (fig. 5-1-10).

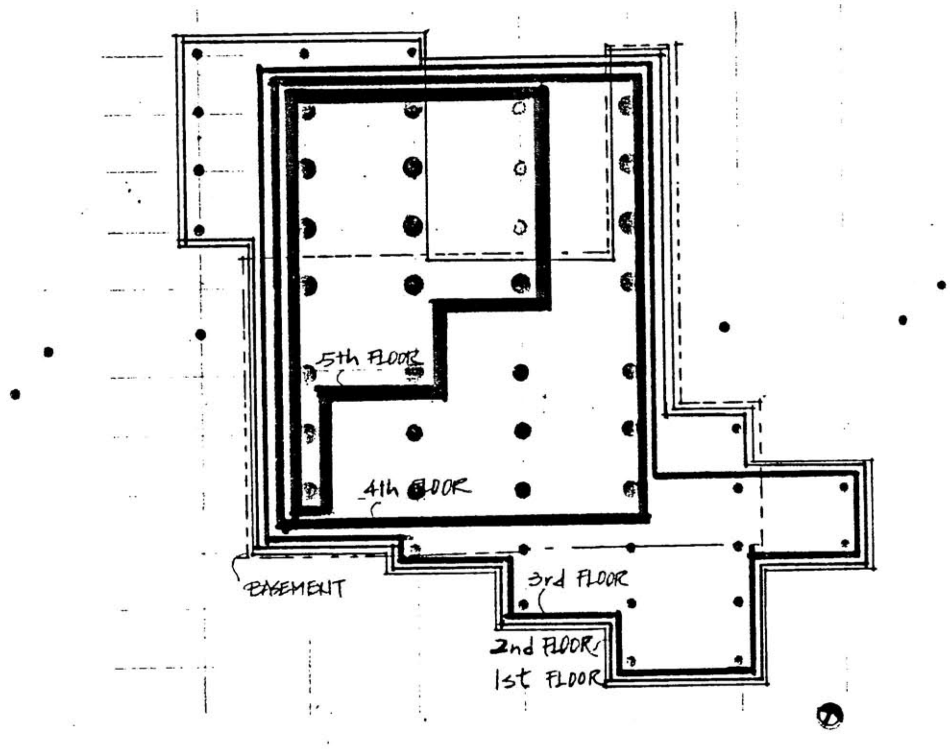


fig. 5-1-10 Boundary lines of colun. grids at each floor overlapped with column scheme at ground level. The diagram shows the relation of different sizes of columns with each floor and the irregular boundary lines as the column grids extend to the perimeter of the building.

A column system, as pointed out in Chapter 1, suggests a virtual spatial form. This virtual spatial form may or may not correspond to the physical spatial form. In conventional classical buildings, rows of columns, in most cases, present a complete geometrical form for the symmetrical rule that governs the dimensional and positional relationship among the columns. As a result, the literal spatial form suggested by the column scheme as a whole, most often, overrides the parts of the virtual spatial form suggested by single columns or modular units which compose the whole.

At the Carpenter Center, the reverse of the above phenomenon occurs. The irregular geometry of the column scheme as a whole lends itself to the reading of the virtual forms of the parts - the column clusters - that compose the whole. This virtual spatial form of the column clusters further gives way to three directional linear spatial form of rows of columns, the perpendicular two orthogonal directions, and the diagonal (fig. 5-1-11, -12).

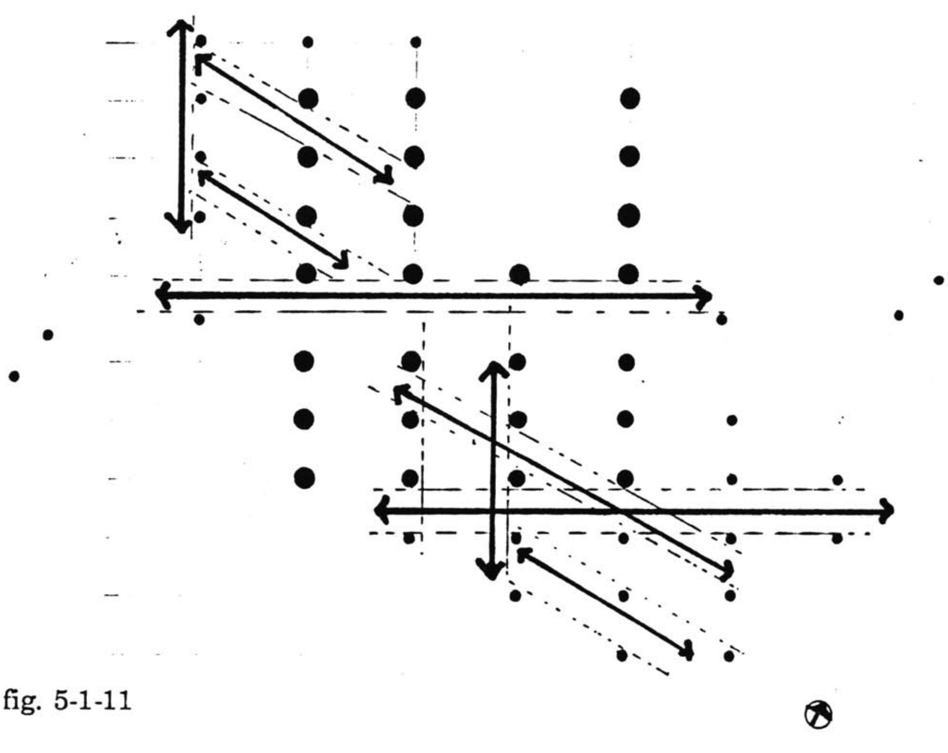


fig. 5-1-11

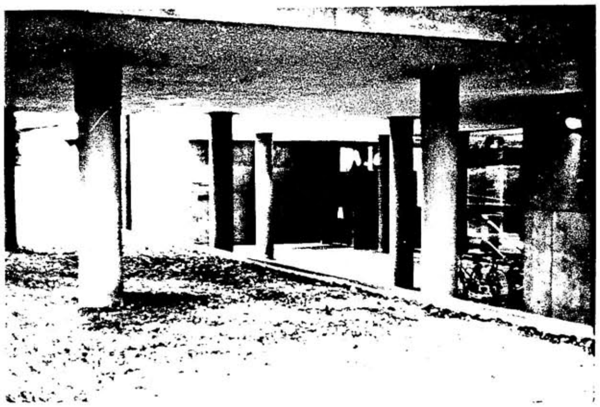
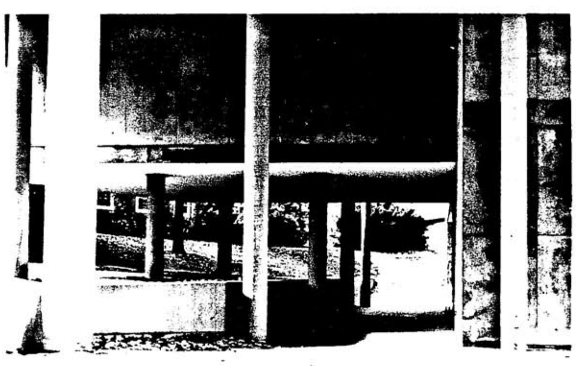


fig. 5-1-12

The three directions of this linear spatial form are differentiated either by their relation with the site and the physical building form or by the positional dimensions among columns. Taking for example, the two east-west promenades at the exterior, we see that one passes under the building along a garden wall at the ground level and one penetrates the building at the third floor, setting forth the spatial form of the east-west oriented colonnades along the promenade (fig. 5-1-13).



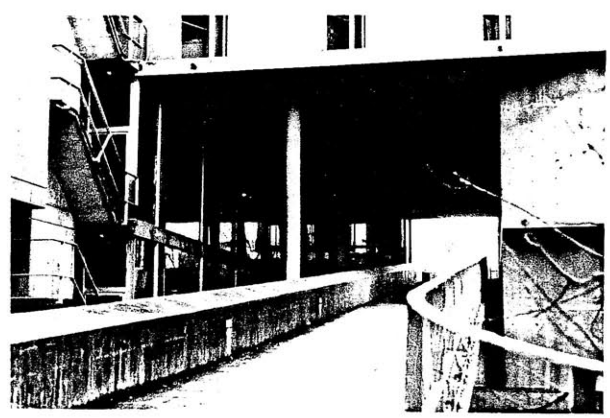


fig. 5-1-13

Otherwise, the dominant linear spatial forms occur at the north-south oriented colonnades where the distance between two columns is smaller than that of the east-west oriented colonnades. At ground floor, this north-south linear spatial form penetrates the glass enclosure and connects the interior with the exterior rows of columns. Here, the virtual spatial forms defined by a series of aligned bays collide with a glass wall, without any reciprocity of the bay system and the physcial enclosure (fig. 5-1-14).

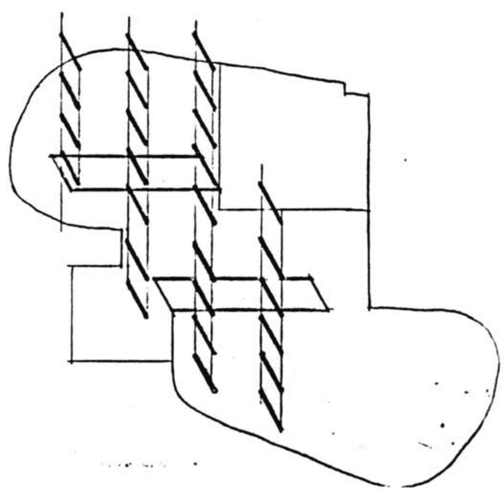


fig. 5-1-14

These linear virtual spatial forms, as dominant parts of the column scheme, however, can transform into other types of spatial forms at varied locations depending on our focal point. For example, at the ground floor of the south-east corner, the linear organization gives way to a cluster of "column-objects". The columns simulate free standing pillars, generating a radiating virtual spatial zone. At the north-west exterior corner of the building, the two directions of rows of columns form a virtual orthogonal spatial form which overlaps with the linear continuity of two rows of columns that go beyond the orthogonal form and penetrate into the building interior (fig. 5-1-15, -16).

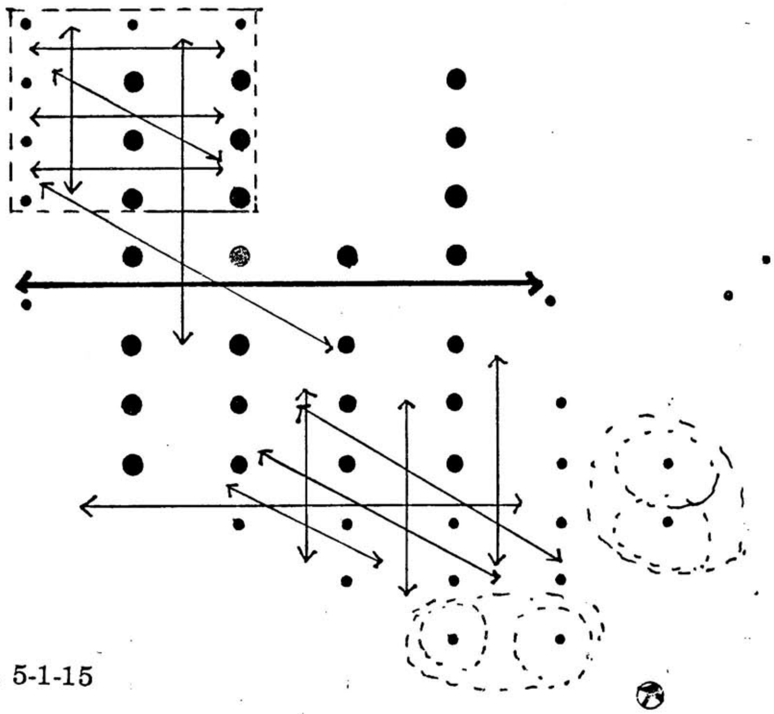


fig. 5-1-15

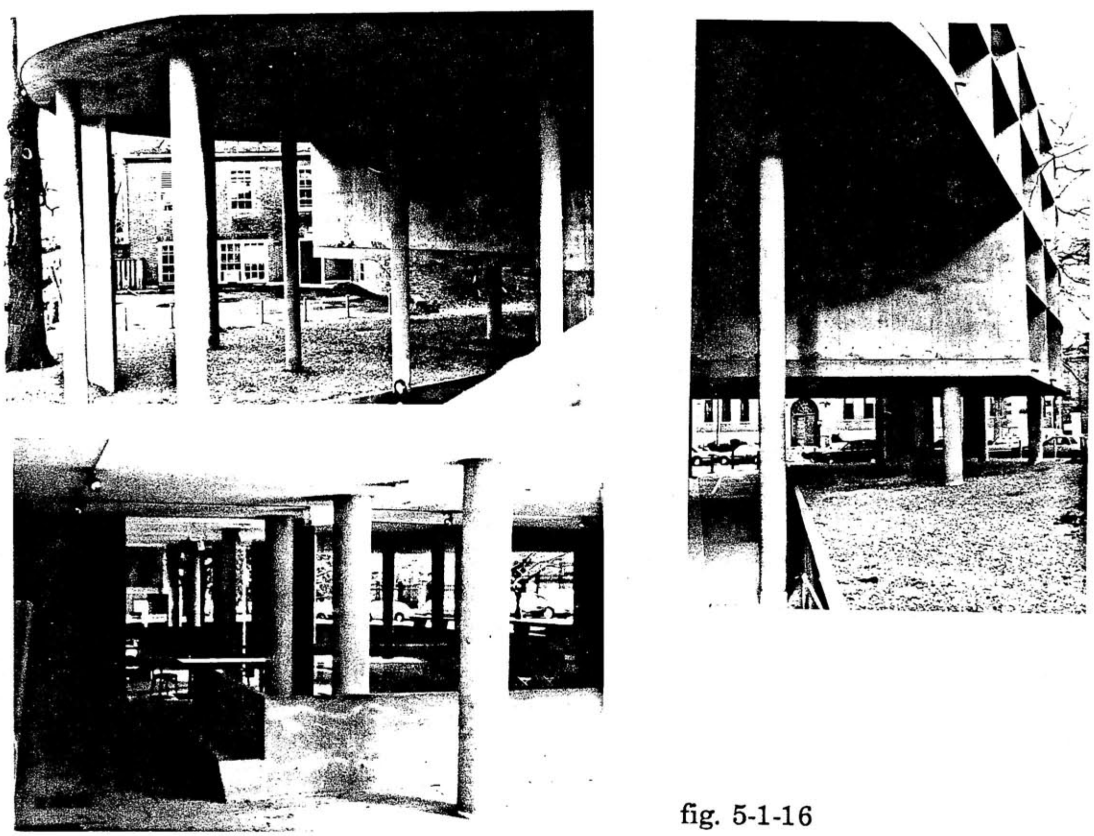


fig. 5-1-16

Accordingly, we may arrive at three types of spatial forms suggested by the column scheme: the linear bay, the orthogonal domain, and the radiating virtual form, each overlapping with each other. The linear bay, however, dominates the other two. The linear bays connect varied spatial zones, including exterior and interior, suggesting spatial movement; the orthogonal domain, defining a spatial zone, contains spatial movement and establishes places, while the radiating virtual ones allow a varied spatial definition, depending on the physical context.

Columns and Walls, The Interface

At the Carpenter Center, we see that the column system is the structural system, while the walls, which are only occasionally bearing walls, are mainly responsible for the physical spatial form. So columns and walls complement each other in forming a program of structure versus space. Within this program, the column system is dominated by orthogonal modular units, and the wall system tends toward a volumetric expression beyond such a rational grid structure.

As formers of the dominant spatial form, the walls influence the reading of the spatial form of columns in two ways. On the one hand, they dictate the positions of the columns while establishing a counterpoint of virtual spatial cues; on the other, they may echo the spatial form of the columns. The former situation applies to the ovoid spatial forms which demand a particular allocation of columns to support the uniquely shaped form. The latter situation applies to the spatial form shaped within an orthogonal column scheme. The orthogonal physical spatial form at the fourth and fifth floors is a straightforward response to an orthogonal central column cluster.

The physical spatial volumes thus present several patterns of relationship to the virtual spatial form of the columns. As mentioned previously, there are three types of spatial form of the column scheme: the linear bay, the orthogonal domain, and the radiating virtual forms. The physical ovoid spatial volumes as they occur at the second floor and the west-wing of the third floor, respond to the three forms by containing the orthogonal and radiating virtual forms. The physical domains respond to the column scheme by being in line with the modular column grids as they occur at the fourth and fifth floors.

Thus the columns, while maintaining their modular grids, are affected spatially by the geometric plan of the walls and the positional relationship with the walls. At one location, we envision a section of a continuous wall subdued to a colonnaded open hall resembling a hypostyle mosque hall, as at the interior of the fourth floor. At the second and third floors of the oval spatial volumes, we see another possibility, as the columns dissolve into a non-orthogonal enclosure composed of various opening devices.

The wall-defined spatial forms are a configuration of orthogonal and oval-shaped volumes stacked onto columns or onto each other. These volumetric parts do not fit into a geometric whole, but instead overlap as separate geometric spatial volumes. Along with the column grids, the circulation among these separate spatial volumes becomes the organizer that connects them. The two vertical stairwells and the exterior ramp leading from the ground level to the third level of the building are the two dominant organizers. Again, these circulation organizers present independent geometrical shapes which either attach to or overlap with the rest of the spatial forms rather than becoming parts of them.

The Dominant Virtual Spatial Form in the Hypostyle Typology

The physical spatial form of the Carpenter Center is a configuration of individual spatial volumes, each of a distinct shape and size, with separate boundary zones. There is no shared central hall that unites these individual spaces. Each of them is a distinct domain relating to each other through shared vertical circulation or horizontal exterior paths.

The arrival at each enclosed space is a separate event through separate entrances or lobbies. These separate events are recognized as happening within a shared building context that is the hypostyle typology. The interface of the colume scheme with the configuration of individual spatial enclosures shows a phenomenal difference between the exterior and the interior.

At the exterior, the reading of the virtual form of columns depends on the adjacent physical context. At the ground floor, the form of the building edge and the landscape affects the reading of the columns as singular poles, as promenades, as clusters of pillars, or as grids. The interior columns at this ground floor, though physically separated from the exterior columns by a glass enclosure, form a literal continuity with the exterior columns.

At the interior, above the ground floor, the dominant spatial typology is the wall-enclosed hypostyle hall. This typology differs from that of the hypostyle mosque in the way columns are correlated to walls. In a Mosque typology, the columns stand out from the perimeter walls, generating a dominant repetitive modular spatial demarcation. At the Carpenter Center, within each enclosed space, there is no physical center or strong spatial demarcation formed by the interior columns. Rather, the attention is drawn to the perimeter shaped by different enclosure devices, which consist of the local virtual space formed by the varied geometry of walls or the varied positional relationship between walls and the perimeter columns, such as the curved wall-contained dark alcove, the sun-baffle defined shaded edges, and the concrete-struts confined domain bathed in filtered light. The columns serve to lead to these virtual spatial zones, instead of asserting strong spatial forms by themselves. This is especially true in the ovoid spatial form of the Carpenter Center, where the ovoid geometry differs from the modular grids of the columns that this ovoid enclosure contains. In other words, in a mosque, the virtual spatial form of the columns dominates the physical spatial form of the enclosure, while at the Carpenter Center the wall-defined physical form dominates and influences the virtual spatial form of the columns.

Furthermore, in Carpenter Center, the column-slab system lacks the orthogonal directional reinforcement which would be conveyed by a column and beam structure such as is present in a mosque column system. The column scheme at the Carpenter Center shows a varied virtual spatial form beyond the literal modular bay.

The decentralization of an individual singular spatial volume in the whole building context, the locality of the virtual spatial form within each individual enclosure and the variation of the perimeter enclosure devices thus are organized as sequential events through the shared hypostyle typology.

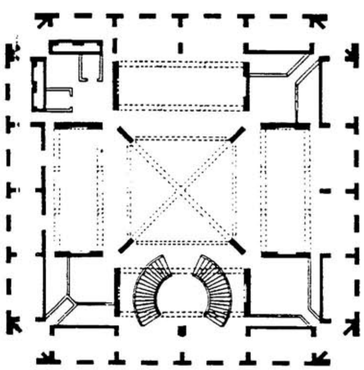
Case Two

Exeter Library

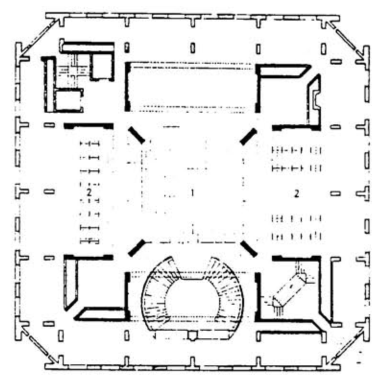
The Three Zones of Structural Systems

Exeter Library is a square, symmetrically shaped building. It consists of four levels of floors above the ground, each eighteen feet high, plus mezzanine space in between (fig. 5-2-1).

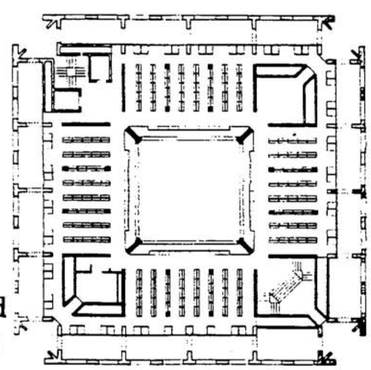
fig. 5-2-1



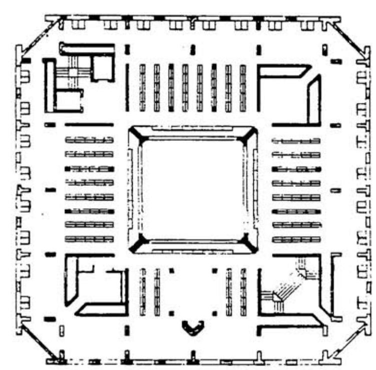
Structural plan



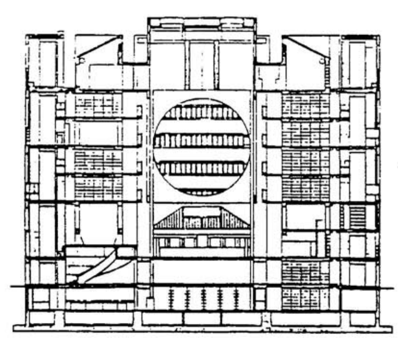
Second floor plan at entrance hall level



Mezzanine between third and fourth floor levels



Fourth floor plan



North-south section, facing east, through main entrance

Concrete and brick walls form the two concentric structures. Bricks as bearing masonry are used for the perimeter zone, concrete for the inner zone. The perimeter zone from the exterior boundary to the inner edge is 15', while the inner zone has equal dimensions of 77'. At the perimeter zone, the exterior brick walls do not form a continuous surface, but instead are penetrated regularly to form piers with a dimension of 5' x 1' at the ground level, which reduce sequentially at each floor to a dimension of 3' x 1' at the fifth floor. The opening between the piers at the ground level is five feet wide, and at the fifth floor, seven feet. (fig. 5-2-2)

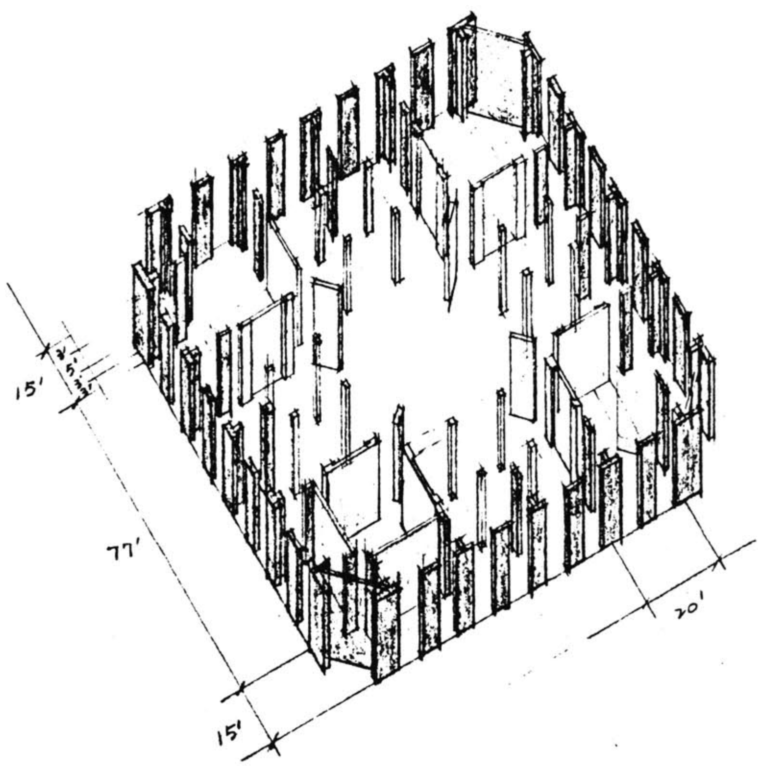


fig. 5-2-2

The exterior pier-wall embraces four elongated bands around the perimeter, each 15' x 80' in dimension. These elongated bands are accentuated by five pairs of brick piers placed perpendicularly against the exterior walls, each defining a 15' x 20' grid. Each set of piers forms like gates along the elongated band, each with 5' wide openings. At each of the four corners of the buildings, pairs of piers interface diagonally with the orthogonal piers and frame a diagonal opening (fig. 5-2-3).

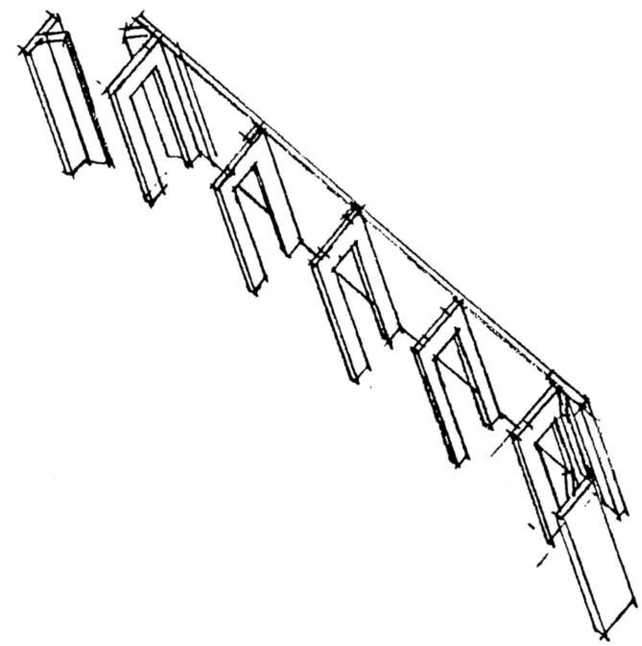
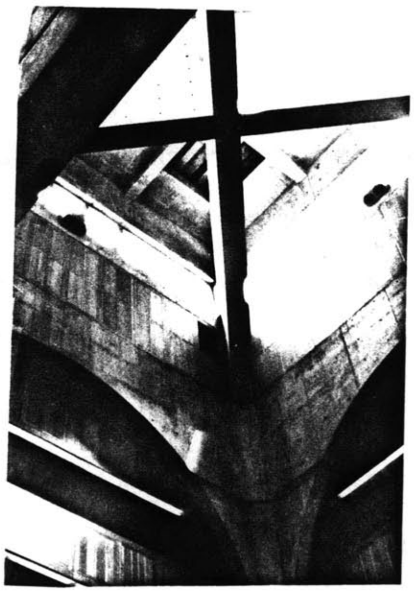


fig. 5-2-3

Four corner service spaces of 20' x 20' are enclosed by both interior concrete and exterior brick walls. Concrete beams run between these service spaces and cover an intermediate zone between a central open space and the perimeter zone. At the ground floor, third, fourth and mezzanine levels, four concrete columns of a dimension of 1' x 1' are placed between the service cores as secondary structural supports (fig. 5-2-4). These columns are omitted at the second level, entrance hall, substituted by thicker beams suspanded between the service cores.

The roof of the central open space is supported by two, crossing diagonal beams carried by four concrete piers of a dimension of 1' x 5'. Wall-like concrete beams, voided at the center by a multi-story circular opening, run around the four central piers (fig. 5-2-4).



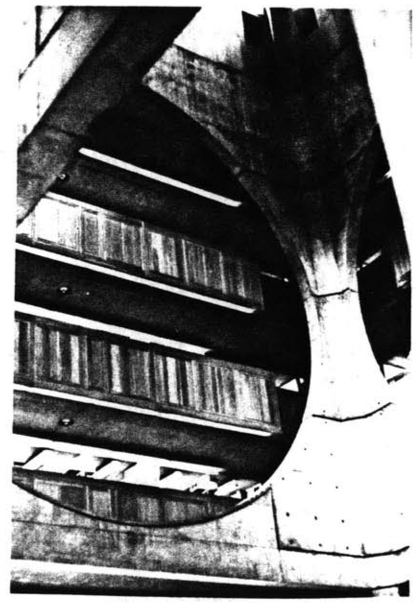


fig. 5-2-4

The three spatial zones, the perimeter, intermediate, and central, thus are differentiated by three distinct structural schemes. The structure at each zone is separated from its neighbor by a margin space of three feet.
These varied structural forms generate varied spatial forms for each zone.

The Three Zones of Spatial Forms

At the perimeter zone, though it is basically a wall structure, the numbers and the dimensions of the openings in the wall transform the planar nature of a wall structure into colonnaded screens in which the openings are equal to the solid.

Five pairs of brick piers attach perpendicularly to the perimeter walls, defining an inner perimeter zone of 12'. Structurally, the set of piers perpendicular to the center are the major load bearing elements, while the exterior walls standing parallel to the center structurally supplement the piers, and function mainly as screen enclosures. The structural scheme of the five pairs of piers acts somewhere between a colonnaded system and a wall system. As a colonnaded system, the five pier sets suggest a progression of space along the longitudinal direction; as a wall system, they generate five subdivided spaces (fig. 5-2-5)

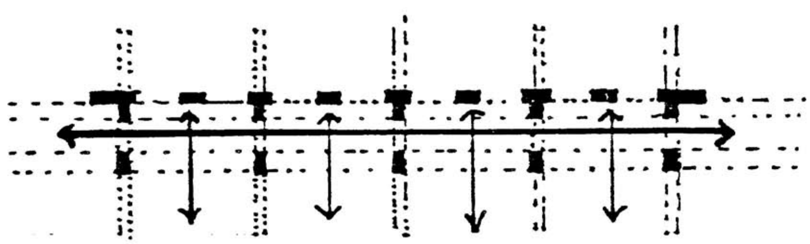


fig. 5-2-5

At the upper floors where the perimeter zone is used as open reading alcoves, there exists two types of spatial directions, one parallel to the exterior walls, the other perpendicular to the exterior walls. The former is dominant over the latter, as it connects the five subdivided spaces into one continuous spatial zone. This dominant direction is enhanced by the exterior walls which circle around the building. The elongated progression within each band combines to encircle the four sides of the building. This encircling movement is partially blocked at four corners by glass infills and wood panels between the piers. These physical enclosures serve to contain each band of the elongated form in which, again, we have five virtually contained alcoves defined by the five pairs of piers. Thus tension between a circling progression and the contained subdivided zones constrain each other in addressing the locality of the perimeter and the continuity among the localities as a whole perimeter zone of the building.

The intermediate zones are defined mainly by four wall-enclosed service spaces. Two hierarchies of virtual spatial forms occur. The one suggested by the walls dominates over the one suggested by the columns or columns and walls. The spatial form suggested by the walls contains an elongated spatial form with openings oriented toward the center and the perimeter of the building. This elongated form, with openings opposite to the elongated direction, suggests a lateral transient nature of the space, instead of a progression along the elongated direction. The four concrete columns generate three square bays, further counter-acting the elongated progression. The structure-versus-space suggestion between an elongated direction and a three-square-bay relates this intermediate zone both to the central square hall and to the perimeter zone with its elongated directionality. This dual-directional nature of the intermediate zone proposes itself as a margin space between the central zone and the perimeter zone (fig. 5-2-6).

The central hall reveals a dramatized presentation of the "structure-versus-space" correlation. The continuing wall surfaces that appear at the exterior facade reappear here, but now composed of giant concrete beams with circular penetrations. The diagonally- placed concrete piers define a virtual square and virtual triangular spaces, both pointing toward a center. The circular penetrations on the wall surface also project virtual circular volumes. The diagonal, the square, and the circle generate ever changing and overlapping illusions of virtual formal connections, outlining the space of the central hall.

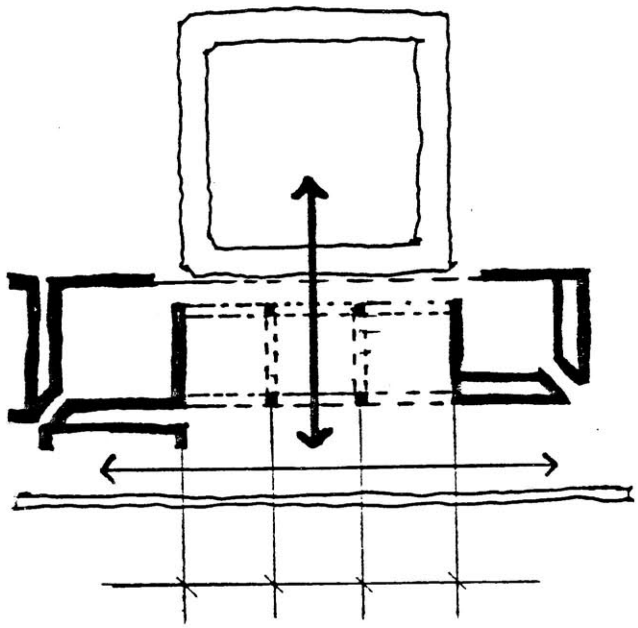


fig. 5-2-6

The structural elements in each of the three zones shape the spatial forms for each zone, while at the same time connecting those of the other zones and forming a geometrical whole. The three zones interface with each other through highly ordered hierarchical layers of interaction between the structural and spatial form. This hierarchy is built on a clear relationship between parts and whole communicated by a complementary interface between solid and void.

The Interface of the Three Zones

The walls, as both support and enclosure, define a dominant spatial form consisting of four corner squares, overlapping with four parimeter zones, the intermediate virtual zones defined the the four serviec cores, and a central square. The diagram below suggests two basic types of spatial geometries. One relates to two orthogonal central axes, the other relates to four perimeter corners (fig. 5-2-7).

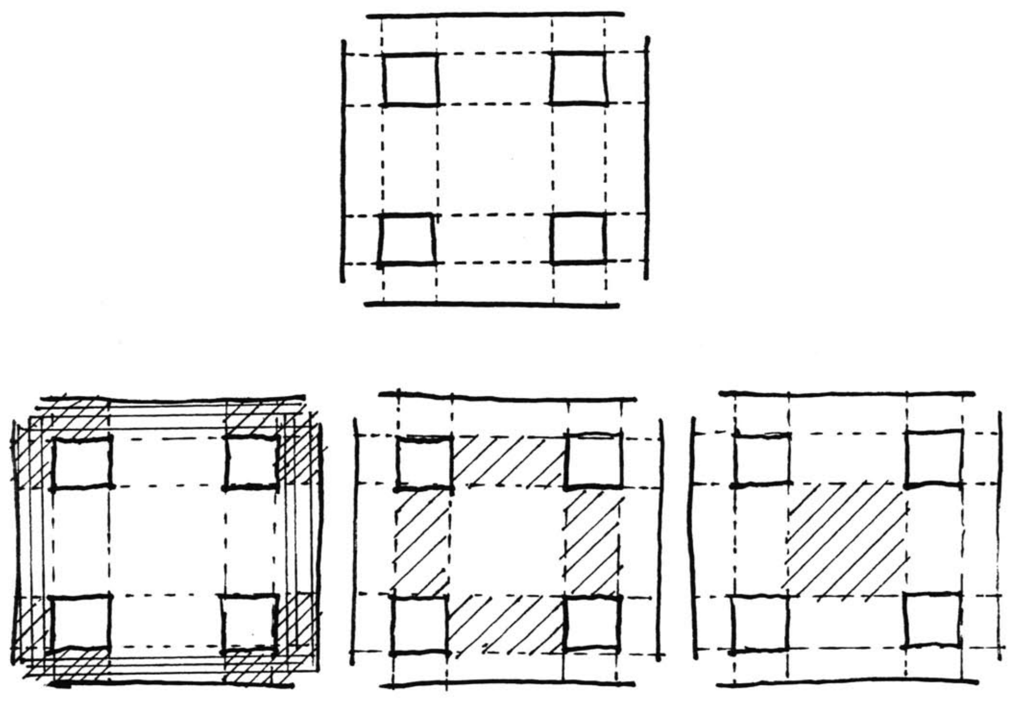


fig. 5-2-7

These virtual spatial geometries become potential structural lines for piers and columns. At the perimeter zone, four pairs of piers are located on the structural lines of the square service area. An extra pair of piers is introduced at the central axial lines. As a result, a continuously encircled perimeter zone is generated, which runs counter to the movement of the central axial spatial form. The perimeter zone becomes pier-encased, with an attached promenade revolving around the two inner zones. The use of bricks for this perimeter zone further enhances the separation of this zone from the two inner zones which are formed by concrete (fig. 5-2-8).

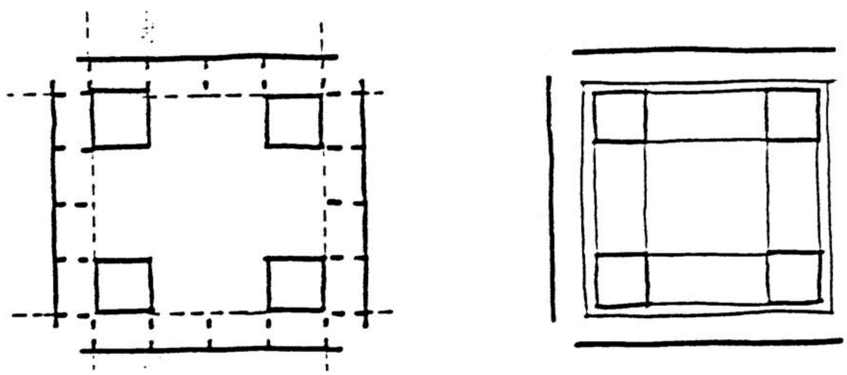


fig. 5-2-8

The four diagonal piers, with both orthogonally and diagonally placed beams, suggest both a separation of the central zone from the two outer zones, and a diagonal connection with the outer zones through the four corners of the building. Thus we see that the piers introduce on the wall- defined spatial form another layer of spatial form which presents three encircling zones. These encircling zones are further divided into four triangles by two virtual diagonals projected from the diagonal beams (fig. 5-2-9)

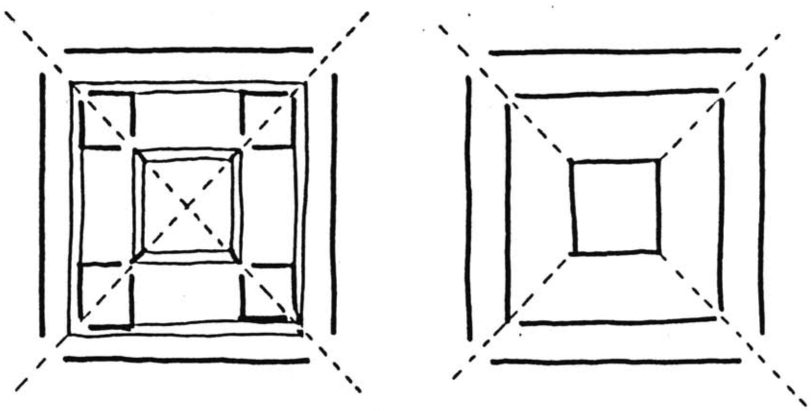


fig. 5-2-9

Walls and piers at the Exeter Library thus articulate individual sets of structure-versus-space relationships at each of the structural zone, while their spatial geometric connection as a whole serves to generate continuity among the localities of each zone.

The Spatial Form of the Piers

At Exeter Library, the virtual spatial form collectively shaped by the three zones overpowers the literal structural form at each zone. The three structure-versus space zones interlock to bring forth a correlated center and perimeter. Piers, as the basic structural elements, play an important role in generating this continuity.

Piers present a different spatial phenomenon than columns and walls. A column marks a point and is subordinate to the surrounding void, and a wall section delineates a physical division and dominates the void, while a pier suggests a directional extension at the same time as it retreats from a literal spatial demarcation contained within the void. A pier acknowleges the presence of the void as much as it is accepted by the void as a potential directional extension. This interplay between solid and void represents a stronger spatial phenomenon in piers than in either columns or walls.

The piers in the Exeter Library generate versatile formal languages expressing the interplay of solid and void. Pier walls, pier gates or piers as colossal columns supporting large roof spans are varied versions of the pier structure.

When a row of piers becomes a pier wall, the spatial quality shifts. As walls, they are intersected by the frequent void intervals, and as columns, they are upset by the strong suggestion of planar continuity. The shape of the light that comes through the openings is responded to by the solid that shapes the light. We confront the solid and void dual nature in the structural form of the pier walls.

These perimeter pier walls are attached by an array of pier gates around the perimeter interior. This array of pier gates can function either as an arcade or a partition and thus resembles the spatial quality of pier walls, that is somewhere between spatial continuity and division.

The pier gate, with the directionality of the piers oriented toward the interior open space, structurally reinforce the perimeter pier walls, while spatially punctuate and interrupt the continuity of the perimeter pier walls. The pier walls accompanied by the pier gates gradually open up toward virtual columns at top, and together with the pier gates, form a colonnaded portico at the fourth floor.

The vertical transformation between walls and columns also occurs at the central zone where four diagonally placed piers extend from linear colossal columns into a planar surface at the upper levels. This planar surface, functioning as beams, forms circular openings as if a continuous wall plane is opened up into the void. As a result, the diagonal piers appear as a continuity of the virtual wall, though, the pier columns generate only open space at the lower levels.

The virtual wall around the central zone and the perimeter are two predominant vertical planes that demarcate the inner and outer zones. The interplay between solid and void in these virtual walls is also present in the way these walls relate to the building as a whole. The margin space between the inner virtual walls and the outer zone, and the discontinuity of the perimeter virtual walls at the four exterior corners, continues the same spatial concern of solid in the void.

Therefore, from the structural elements of the piers, to the constituted structual form of the virtual walls and gates, and finally to the building form as a whole, we see a strong continuity in the spatial form based on the interplay of solid and void.

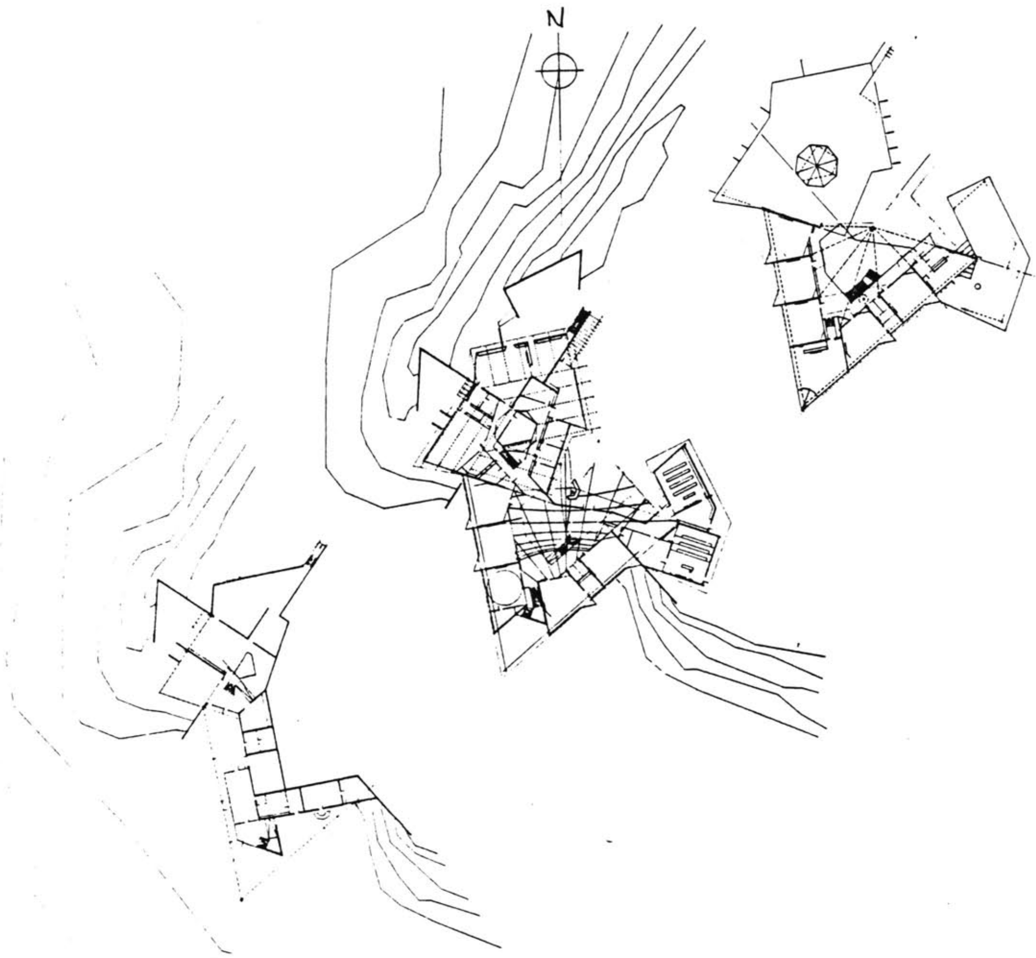
In this continuous whole, the center and the perimeter support and respond to each other, though they present different structural forms at each zone. This simultaneous emphasis of the center and the perimeter is different from a wall enclosed hall such as a pantheon or a column-defined pavilion. A pantheon tends to address the center, and a pavilion the perimeter. The piers in the Exeter Library, when viewed as a structural form somewhere between columns and walls, and as the generator of the dual spatial quality of solid and void, create a place where both the center and the perimeter call for attention.

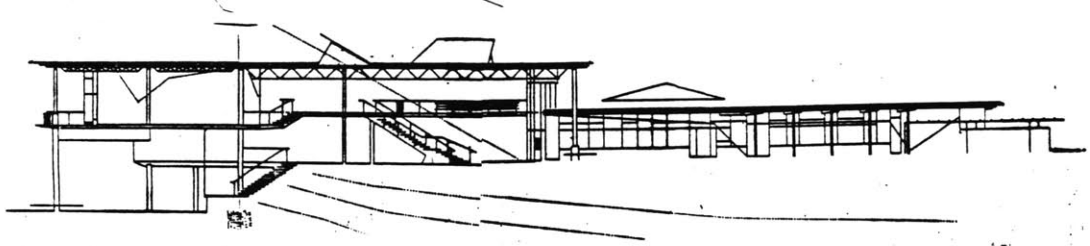
Case Three

Lorch High School

The Three Clusters of Spatial Form

Lorch High School is built on a hillside with slopes rising from south to north (5-3-1).

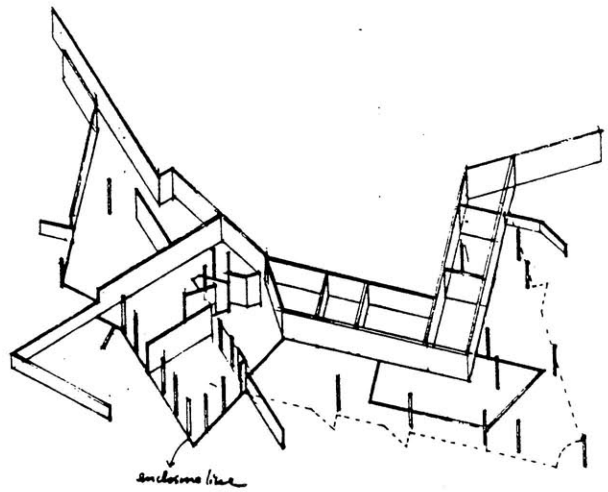




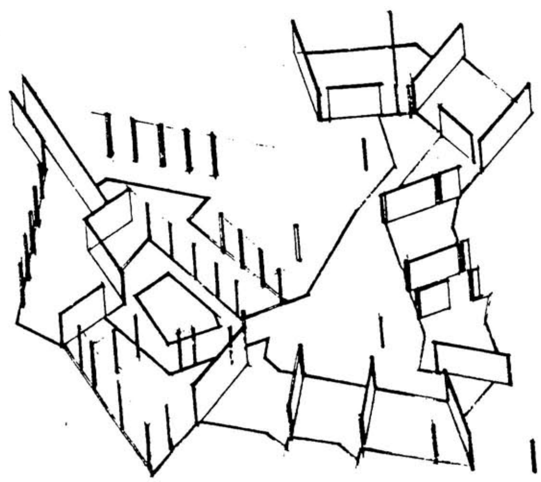
North-south section, facing west, through entrance hall

The column system, wall system, and column and wall systems are all adopted in this building (fig. 5-3-2).

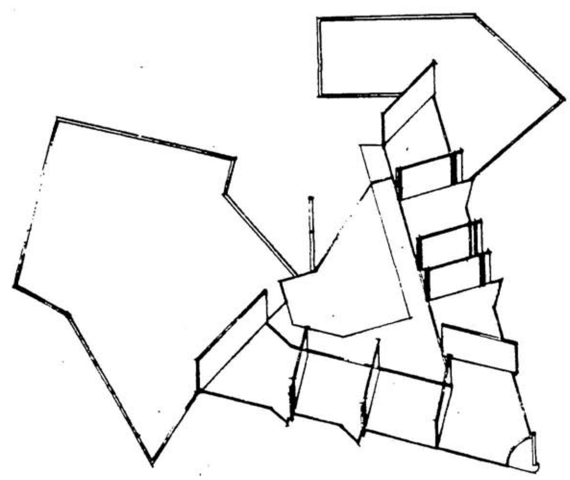
Ground floor



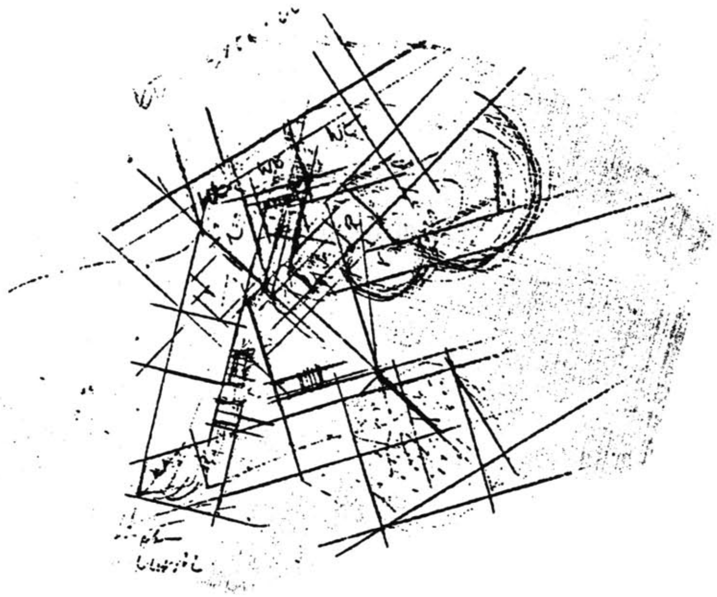
Second floor



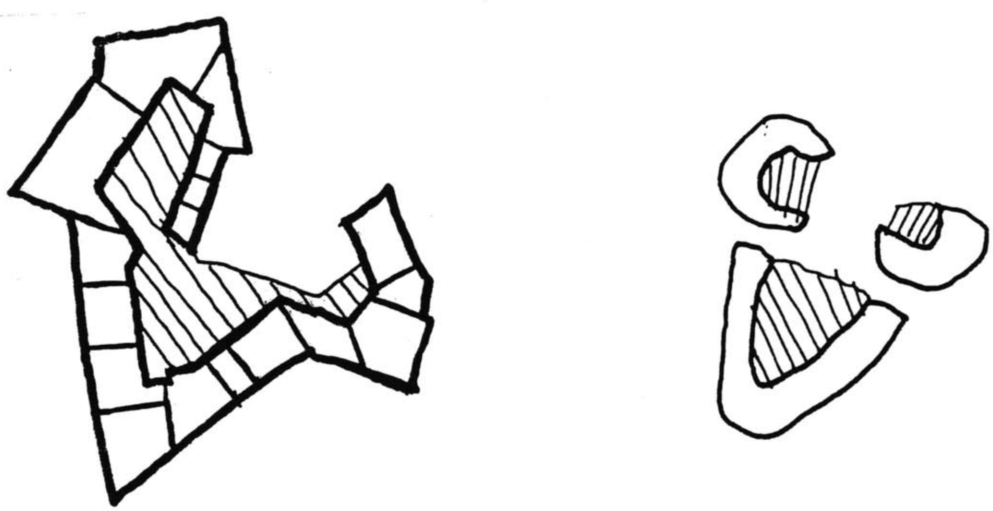
Third floor



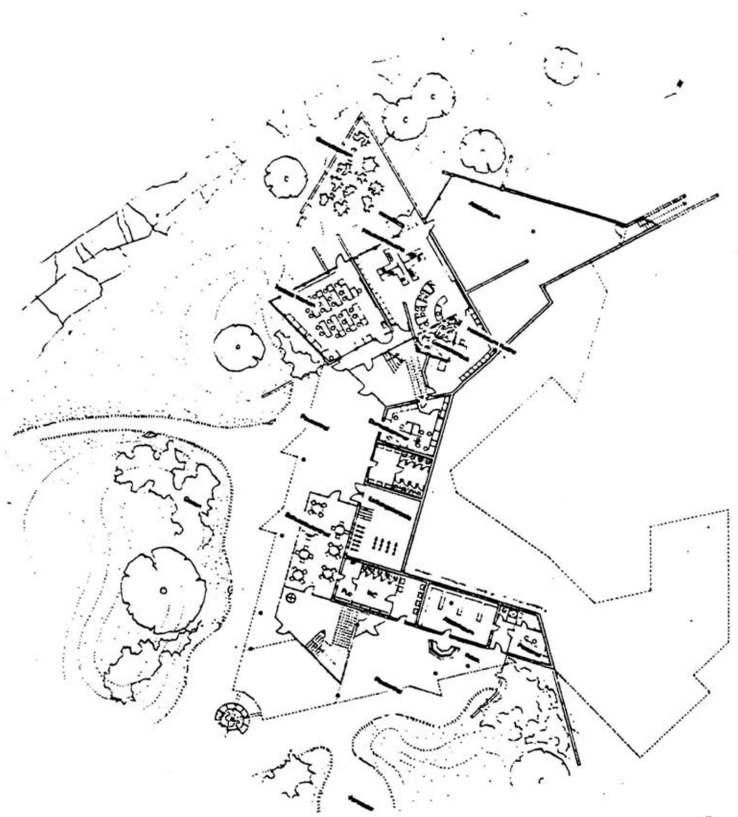
The building is basically composed of three clusters of spatial configurations, at north, south and east. (fig. 5-3-3).



By cluster, I refer to the presence of distinct geometric entities, each sharing a similar typology of subdivided spaces arranged around a central lobby (fig. 5-3-4).

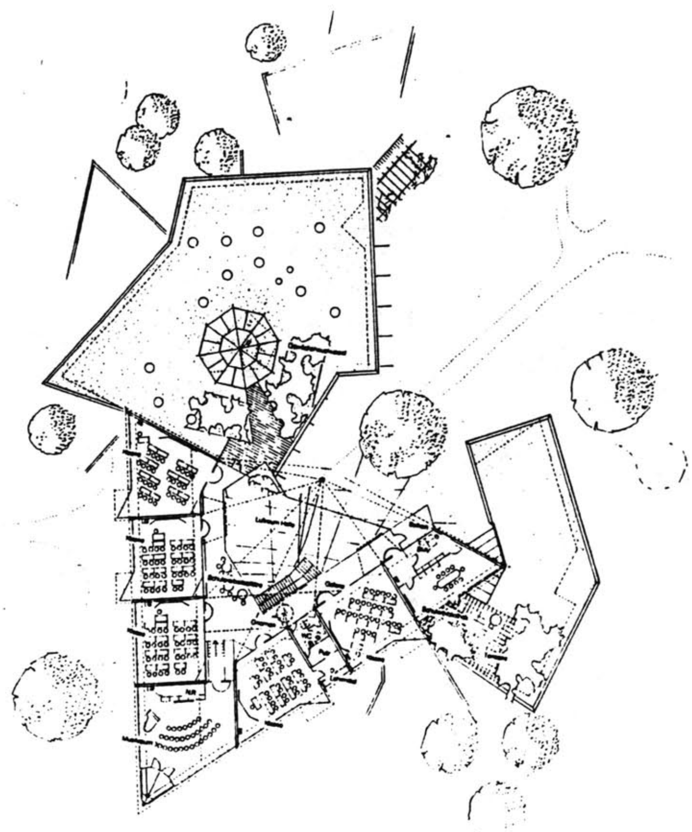


The south cluster, which rises three stories at south side and two stories at north side, is the central cluster dominating the other two with respect to size and position. Shaped in a triangular form, this central cluster is supported by concrete columns at the south side and a steel pole at the north side. The two-story north cluster is supported by concrete columns and walls, and steel columns. The one-story east cluster has a concrete wall structure. These two smaller clusters do not present distinct geometric shapes. The ground floor of the two south wings of the central cluster is defined by colonnaded corridors, while the second and third floors are enclosed by classrooms. The lobbies of the north and south clusters are defined by classrooms lining up around the perimeter of each cluster (5-3-5).



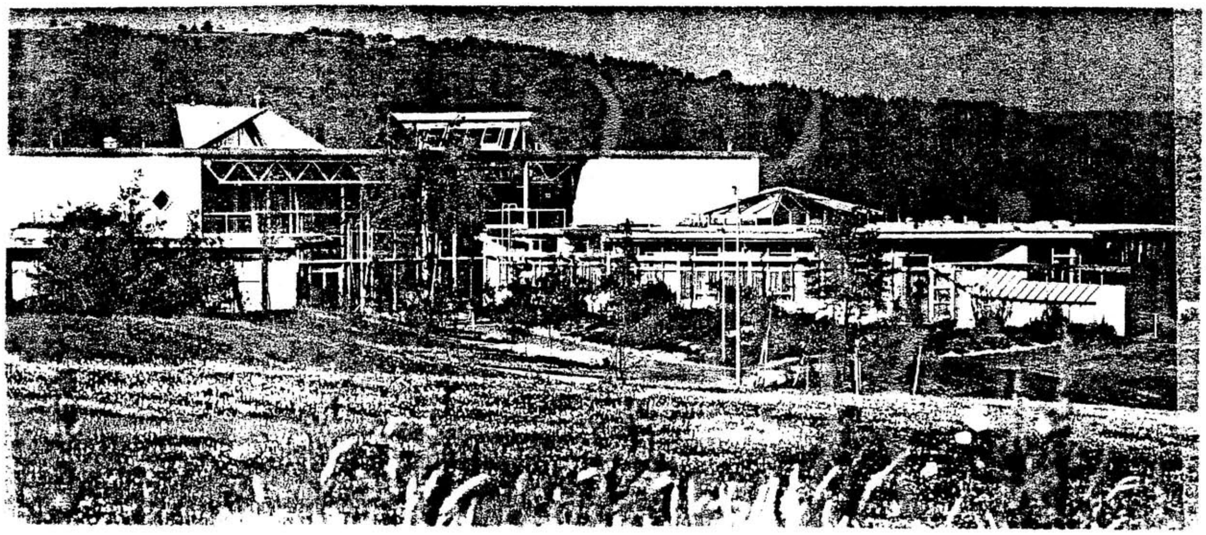
Ground floor

Second floor

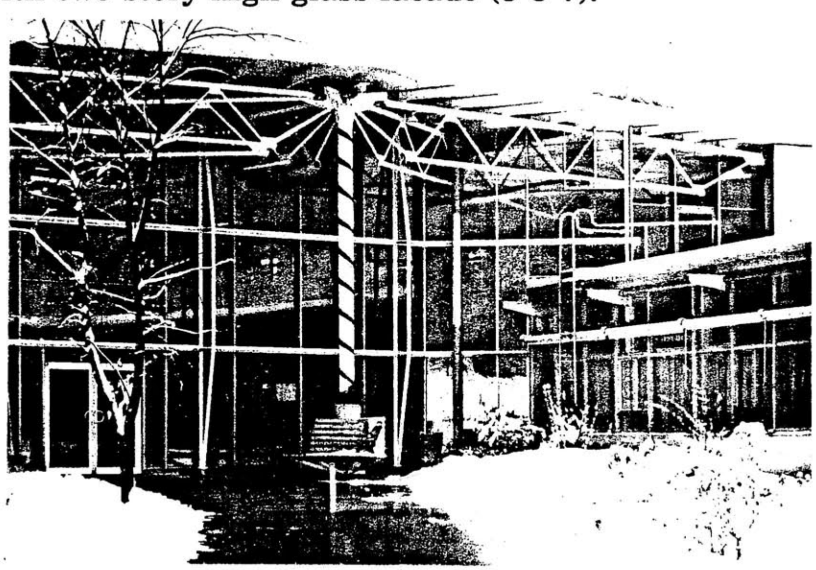


Third floor

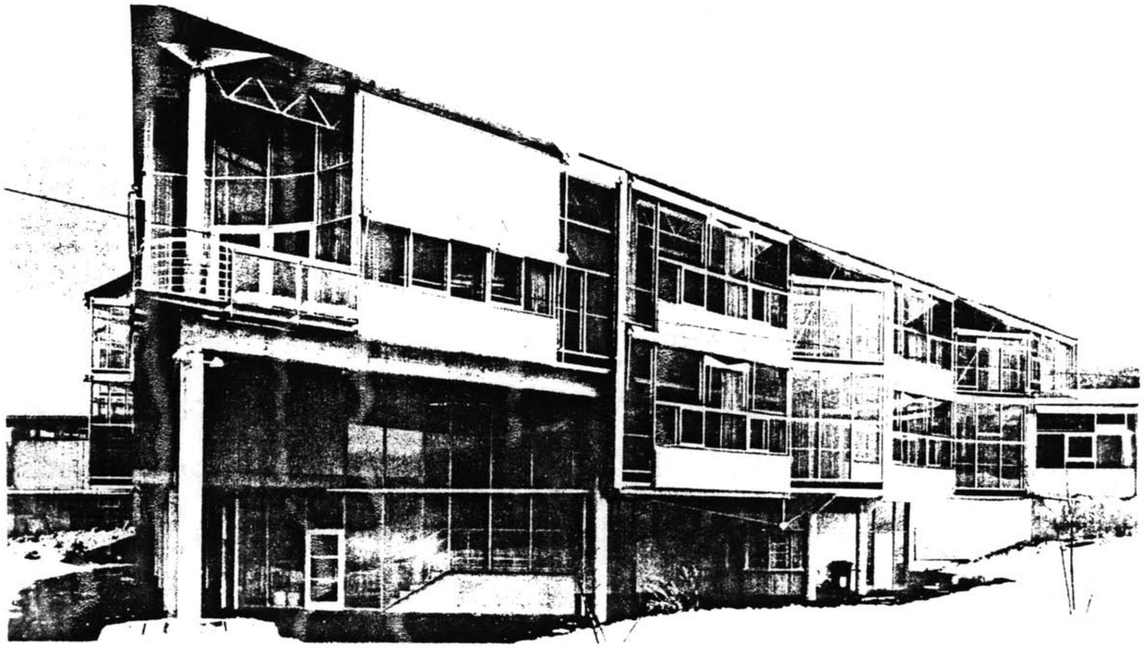
There are two important entrances to the building. The entrance at the north is the main enctrance (fig. 5-3-6).



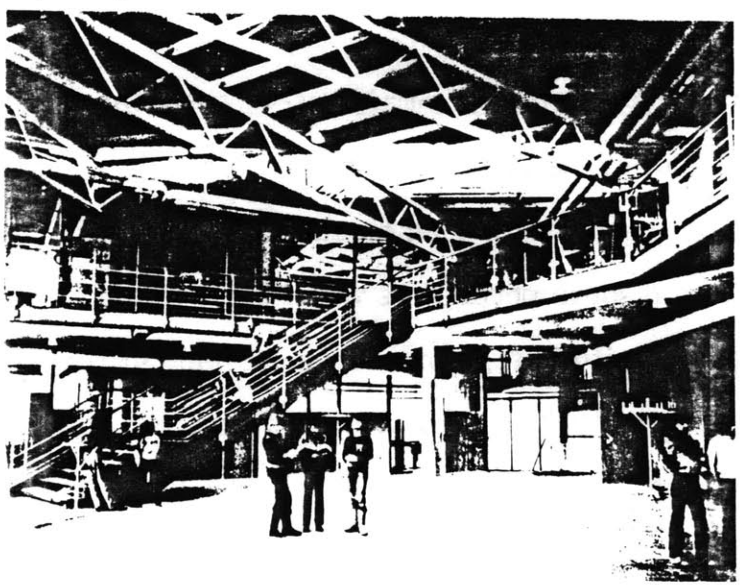
It is fronted by a steel-pole supported portico and leads to the central hall which is enclosed with two-story high glass facade (5-3-7).



From the central hall, we can proceed to the lobbies of both north and east clusters. Another important entrance is located at the south point of the triangular form (5-3-8).



It leads to a small lobby with a staircase winding up to the second floor connecting to the central hall where a central staircase further leads to the uppermost floor (5-3-9).



The north cluster also has a major local entrance form the south side of the ground floor leading up to the second level. Along the perimeter of the ground floor at each cluster, there exist other local entrances which lead to individual classrooms.

The East Cluster, Wall System and the Correspondence of Physical and Virtual Spatial Form

The east cluster is a one-story wall-supported spatial form. Sections of wall planes, either in a parallel position or at certain angles, define a series of rooms which gather around a small lobby, connecting with the central lobby. Openings facing both exterior and interior are enclosed by a secondary structure of glass and wood panels. The secondary structure corresponds to the virtual form suggested by the walls and is basically dependent on the walls as supports. There presents a simple, straightforward structure-versus-spatial relationship.

The South Cluster, Hierarchies of Structure-versus-Space Form

At the ground floor of the south cluster, concrete walls form two strips of elongated enclosed spaces, set perpendicular to each other. One row of columns runs at both west and south perimeters with beams connecting to the concrete walls in orthogonal position. The one-row colonnade at the west side suggests a virtual spatial form which is subordinated to the wall-defined physical spatial form. In general, there are no dominant dimensional modules between the distance of two columns.

At the south side, the colonnade defines an independent virtual form which intrudes, diagonally, into the orthogonal wall-enclosed spatial form, and, together with the west-side colonnade, merges into a virtual triangular form which is physically enclosed at the second and third floors (fig. 5-3-10, -11, -12).

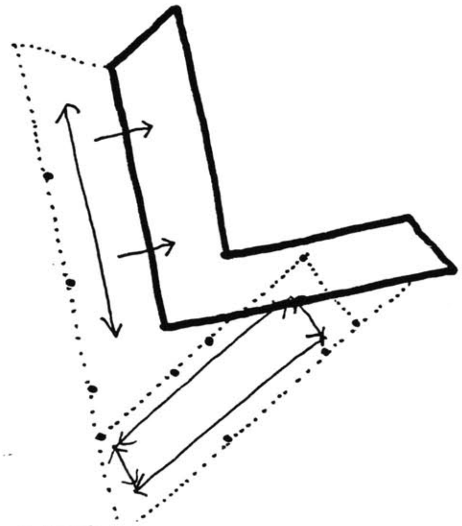


fig. 5-3-10

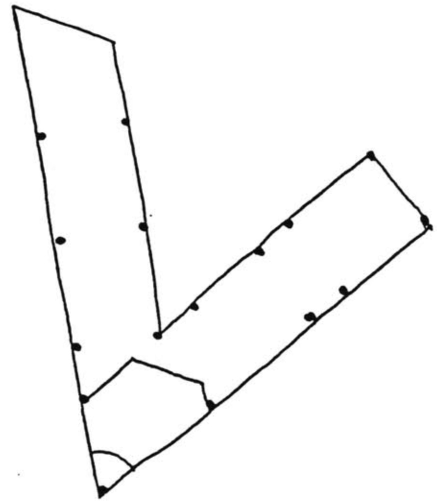


fig. 5-3-11

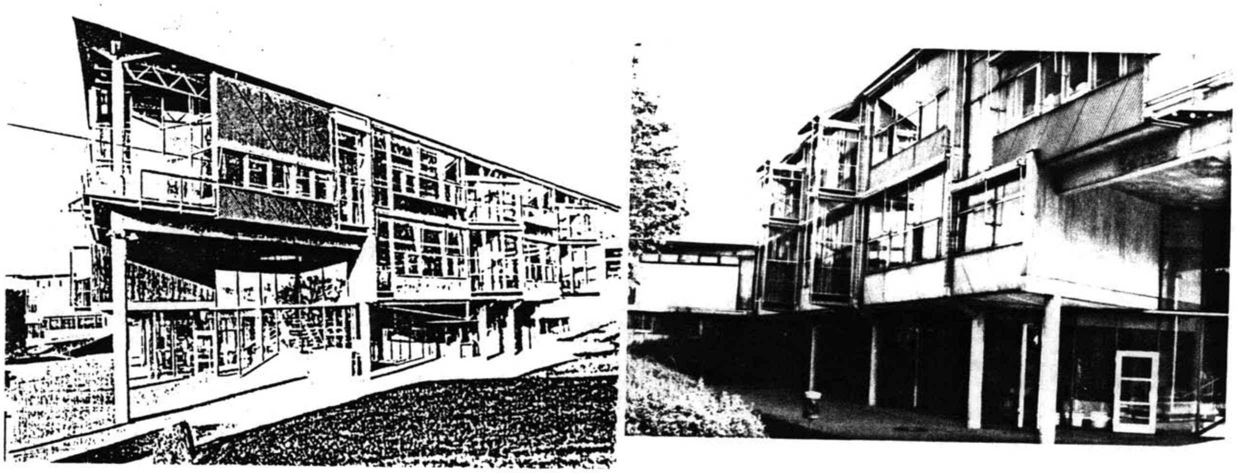


fig. 5-3-12

The change of angles forces an intrusion of the columns into the wall-defined space at the south side. We see a column standing at the center of a physically enclosed room, without any positional and dimensional relationship with the walls.

At the second floor, the structure changes from a column-wall system into a column system with both concrete and steel columns. An inner row of concrete columns grows upon the walls of the ground floor (fig. 5-3-13).

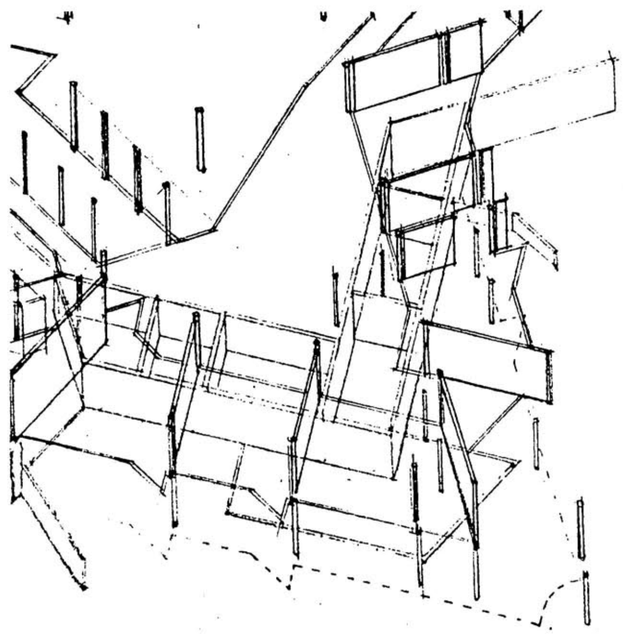


fig. 5-3-13

This inner row of columns, together with the outer row of columns, suggests two bands of elongated virtual spatial forms which define two sides of the triangular whole. The two bands of elongated spatial forms are subdivided by brick walls between the columns; enclosed by glass at the exterior facade and wood panels at the interior facade. This physically confined triangular spatial form, composed of two bands of elongated rectangles, recurs at the third floor.

Besides concrete columns, the other major support for the triangular spatial form is a steel column at the north side rising two-stories high. Steel trusses supported by this steel column fan out toward the interior to join with the concrete columns (fig. 5-3-14, -15).

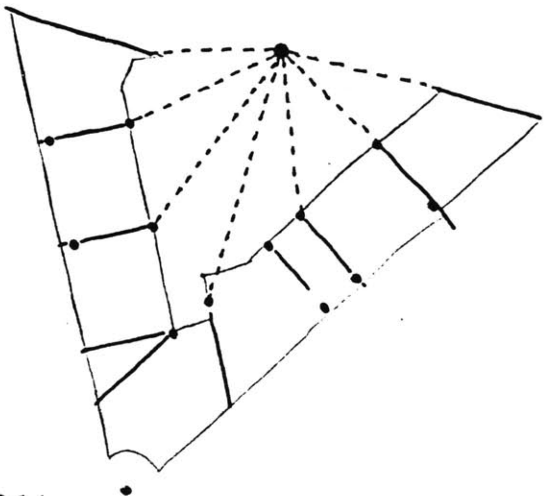
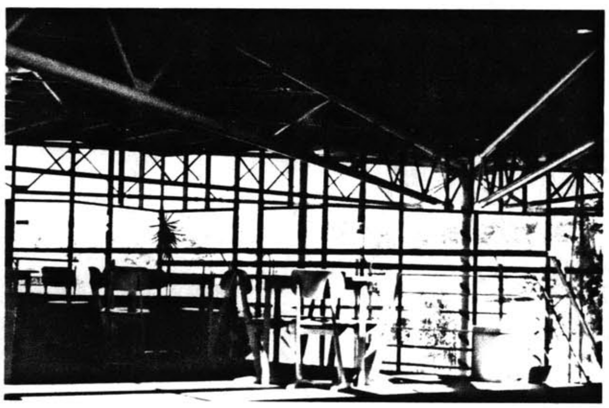


fig. 5-3-14



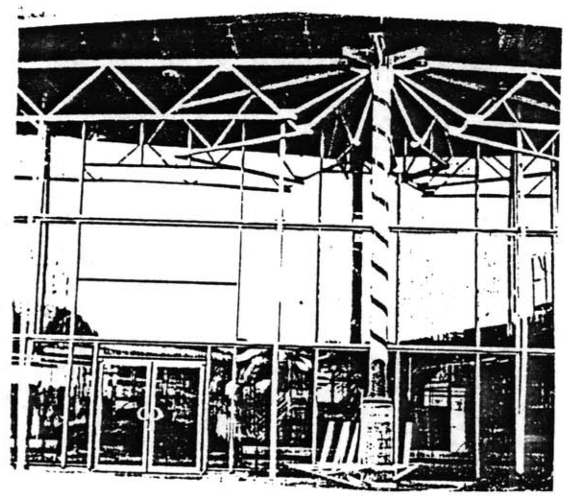


fig. 5-3-15

Together, the concrete and the steel columns support a roof. The steel column is a singular pole which does not suggest any literal spatial form relating to the triangular spatial form. The concrete column scheme as a structural counterpart of the pole is the major element that defines the triangular spatial form.

Though the singular pole is of the same hierarchy as the concrete columns structurally, as a spatial scheme it is equal to the sum of the concrete columns, and is therefore at a higher structure-versus-space level than a singular concrete column. The concrete column scheme provides for a physical triangular spatial form, which is again dominated by the virtual spatial form shaped together by the pole structure and the column scheme. This virtual spatial form, relating to the open space shaped by the three building clusters as a whole, suggests a varied possible spatial geometry that may occur around the steel pole and between the pole and the columns. The steel pole resembles a pillar generating an ovoid zone around it, dominating the virtual open space (fig. 5-3-16).

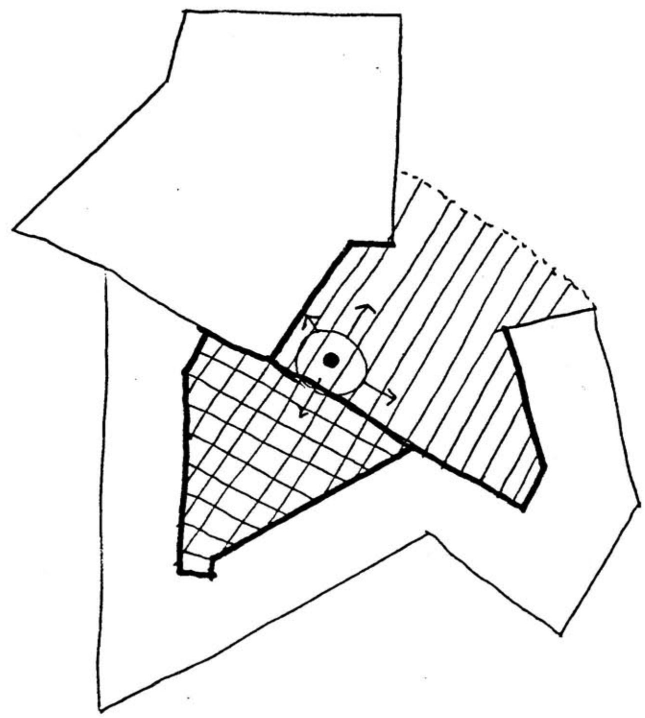


fig. 5-3-16

A glass facade physically divides this virtual space into two domains, an enclosed lobby as a dominant part of the enclosed triangular form and the exterior portico entrance. This two-story glass facade excludes the pole at the exterior. The pole thus generates a radial exterior domain around it as a counterpart to the enclosed central lobby.

The two-story glass facade has an indirect structural relationship with the steel pole. It is supported by a frame of steel mullions, which is again supported and strengthened by vertical steel trusses, which are fixed on the ground and the ceiling. The zigzag form of the glass facade further helps to stabilize the facade structure. In such a way, this glass enclosure is not only structurally semi-independent from the steel pole, but also is free from the virtual spatial form of the pole (fig. 5-3-17).

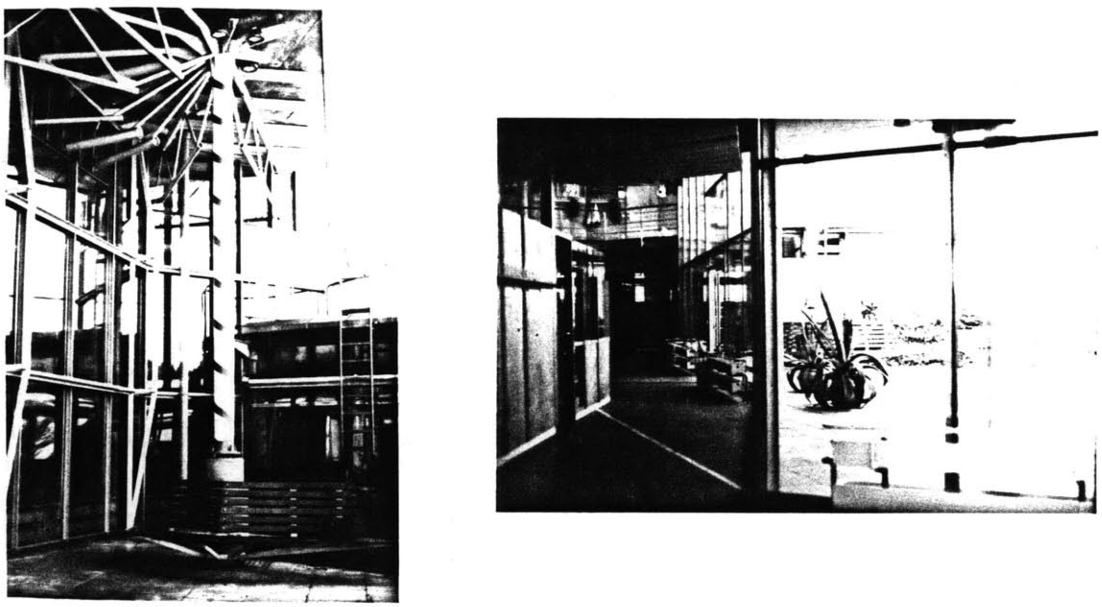


fig. 5-3-17

The glass facade completes the physical enclosing of the triangular spatial form which is suggested by the concrete column scheme. This glass enclosed triangular spatial form is again, as mentioned previously, subordinated to the virtual space confined by the three building clusters in which the steel pole occupies a central position. The extension of the roof from the glass facade to the exterior pole visually expands the interior volume beyond the physically enclosed space toward the virtually defined space.

The North Cluster, The Overlay of the Physical Spatial Form and the Virtual Spatial Form

At the north cluster, steel columns are used in coordination with concrete columns and walls. Again there is no consistent geometric relationship among these structural elements.

At the ground floor, a prolonged retaining wall from south to north forms one edge of the building. Two other retaining walls branch out from the spine retaining walls at the west side. These retaining walls show a zigzag, meandering linear growth. The two concrete retaining walls, along with a third wall section, suggest three subdivided virtual spatial forms at the west side (fig. 5-3-18).

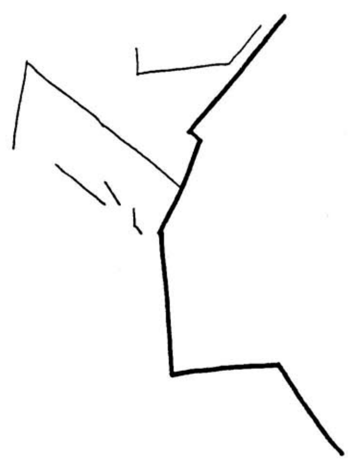


fig. 5-3-18

Because of the prolonged extension of each wall section, these zigzag walls form planar walls rather than containment-walls. They partially define and enclose both interior and exterior spaces and define a context of sub-divided rooms rather than the building cluster as a whole.

Planar walls work with the zigzag walls in defining space. The case occurs at the entry stairwell of the ground floor where a third section of planar wall interfaces with the space defined by two parallel walls (fig. 5-3-19).

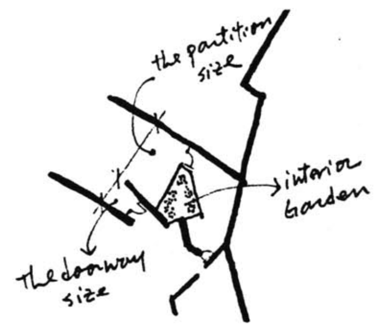


fig. 5-3-19

The narrow opening defines a doorway, the wide one an interior facade. Sequential interfacing of the walls set at an angle to the larger spatial domain occurs again with the third section of the wall, introducing an opening toward an interior garden.

The concrete walls suggest virtual spatial form which is overlaid by another layer of structural form, the exterior facade and interior partitions, supported by square concrete columns. Square concrete columns are placed on the floor line of the exterior facade and interior partition walls as supports for the secondary structure, glass and wood panels. These secondary structures enclose a physical spatial form overlying the virtual form suggested by the zigzag concrete walls (fig. 4-3-20).

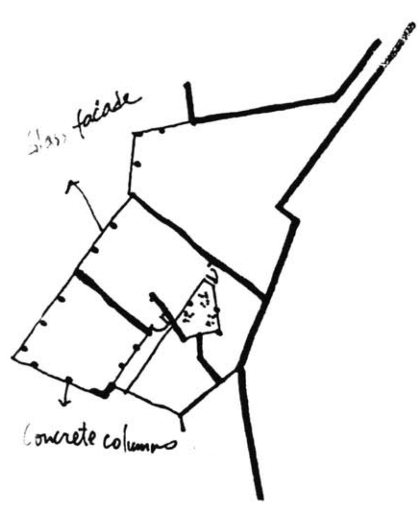


fig. 5-3-20

Together the concrete columns and the secondary structural enclosure form a virtual planar form as both a structural and spatial counterpart to concrete walls. This forms a structural counterpart, since the concrete walls are insufficient as an independent structural scheme, and have to work with the concrete columns in the role of roof support. They form a spatial counterpart in the sense that the physical enclosure is independent from the virtual spatial form suggested by the concrete walls. A separate spatial domain is generated, overlying that of the concrete walls.

The scheme of the square columns as "facade columns", that is positioned in line with the facade, thus is determined by the spatial geometries formed by secondary structural elements, such as glass or wood panels, instead of that of the other primary structure, concrete walls. These "facade columns", also form a zigzag enclosure. Although coordinating with the concrete walls as parallel supports, the "facade columns" do not depend on the concrete walls for support, nor are they constrained by the walls in spatial disposition. They can be considered an independent planar wall extension. As both independent and parallel structural elements with the concrete walls, the position of the "facade columns" can form varied geometrical shapes, rather than only a straight orthogonal alignment with the walls. In other words, they may either complement the virtual spatial form suggested by the wall scheme, or violate it by overlapping a varied physical form on the virtual form suggested by the walls. Both cases occur at the north building cluster.

As independent spatial form, concrete walls and "facade columns" suggest individual virtual spatial form. The overlay of both generates a third layer of physical spatial forms. This column and wall system is atypical in that the columns and walls do not reinforce each other in spatial geometries, but rather each generates an individual virtual geometry in forming the whole physical configuration.

At the second floor of the north cluster, the concrete columns continue as steel columns, which cooperate with concrete walls in supporting the roof (fig. 5-3-21).

fig. 5-3-21

Two types of columns, steel wide flanges and steel tubes, are employed. Also two types of structural principles are involved. In one type, beams connect steel columns and concrete walls; in the other type, beams connect wide-flange steel columns and tubular steel columns. In general, the wide-flange columns are placed around the perimeter of the interiors, while the tubular columns are placed at the inner zones.

The steel columns form a modular structural scheme of elongated bands each three meters wide. These three meter intervals are the short sides of the virtual, elongated spatial forms. At the long side, columns are placed in irregular distances. Groups of elongated parallel strips of varied orientation configure around an L-shaped wall structure (fig. 5-3-22).

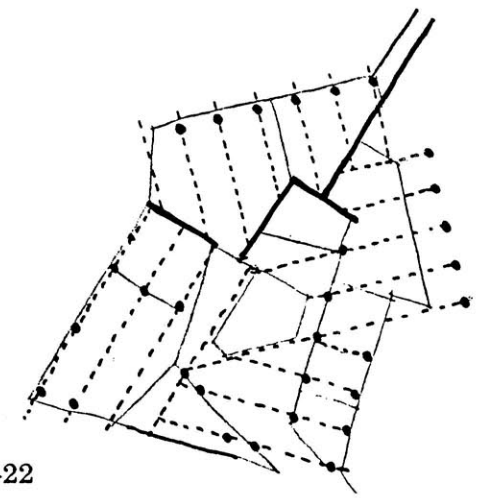


fig. 5-3-22

This wall structure opens towards a green house at the south and is backed by an extended wall which reaches the exterior at the north. Like the steel pole at the entrance, the L-shaped wall structure defines a central zone. However, in this case, in contrast to the pole structure, a reverse structure-versus-space phenomenon is demonstrated. Here, the walls are internal; while the pole at the entrance is surrounded by open space. The column scheme around the L shaped walls responds more to the exterior facade than to a unified internal structure. Most of the beam directions are perpendicular to the exterior facade and are placed three and one-half meters apart around the perimeter, while the steel pole is a central structure that collects the steel truss beams in a radial pattern (fig. 5-3-23).

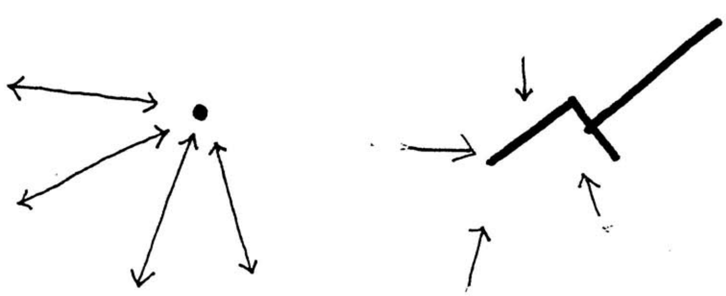


fig. 5-3-23

Diverse virtual spatial forms come together at the L-shaped wall. There emerges a dominant physical enclosure formed by two close-to-square angles placed in rotation to each other (fig. 5-3-24).

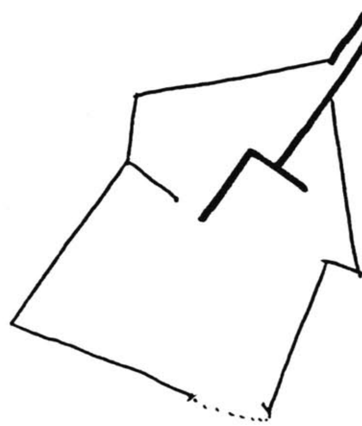


fig. 5-3-24

This dominant physical enclosure also presents a semi-independent structure-versus-space relationship with the central wall structure, similar to that of the ground floor, but carrying further a situation where the physical spatial form as a whole has nothing in common with the varied virtual spatial froms shaped by the individual structural column scheme.

Layers of Structural and Spatial Forms

The structural scheme at Lorch High School is as a whole, non-orthogonal, consequently, the dominant organizer of the relationship among the clusters is the hierarchy of the cluster typology, either in terms of spatial or structural forms.

The steel pole forms the highest level of structure-versus-space relationship in respect to sizes. The steel pole and a set of concrete columns generate the dominant triangular spatial form of the central cluster composed by a central lobby and a series of partitioned spaces. This dominant triangular spatial form is flanked by the east and north clusters of smaller sizes. The primary structure at the east and north clusters relates more to the size of subdivisional spaces than to the size of the building clusters. These subdivisional spaces present independent geometric spatial patterns and together form the whole cluster around small lobbies which are subordinated to the central lobby.

The primary structure generates virtual spatial form which depends on secondary enclosure, glass, and wood panels, to complete the physical formation. These enclosures respond to the virtual spatial form in two ways. The secondary enclosure may be semi-independent from the primary structure and generate physical spatial form by itself, as happens with the glass facade at the entrance, which forms the major section of the enclosure for the dominant triangular form. Contrariwise, the secondary structure may be dependent on the primary structure as occurs with the enclosures that are supported by concrete columns.

Thus, the physical enclosure as secondary structure can be either independent or dependent on the primary structure in forming space. The structurally independent enclosure structure such as the "facade columns" or the glass facade at the entrance, generate vried geometric form overlying on the virtual form of the primary structure. The enclosure structure thus can be independent from and parallel to the primary structure not just structurally, but also spatially. Complex layers of spatial and structural forms are the result.

The Prominent Virtual Spatial Form

The layers of structural and spatial form at Lorch High School generate the predominant virtual spatial form. Varied spatial domians overlay with each other, especially the jopen halls and lobbies. The non-orthogonal spatial geometry and configuration add up to a weak demarcation among these open spaces. As a result, though different halls or lobbies are housed under different building clusters, the spatial continuity from one lobby to the jother is ever present. The central hall can be simultaneously read as an ovoid open space which includes the exterior open space, a linear procession which indludes the east and north lobbies, or a self-contained triangular hall excluding a connection with adjacent virtual spaces.

The varied roof structure and roff height, as well as the varied facade and partition walls that define these open spaces, are subordinate to such a strong virtual continuity of the "lobby" spatial typology.

The "lobby" typologyb resembling the Exeter Library is organized around a center and a perimeter. However, at Lorch High School, the connection of the central halls with the other adjacent smaller lobbies supports a diversified distribution of centers, even though the size and the position of the central hall physically dominates athe other smaller lobbies. The continuous flow of the open spaces leads to an interior linear progression through the lobbies. This progression at one side moves along the interior facde of the cell spaces, and at the othe side, opens to the exterior through the glass facade at the north.

This cell spaces shape not only the virtual interior open space, but also the virtual exteior open space. Around the exterior perimeter, we also confront various virtual domains defined by a non-orthogonal relationship of the perimeter walls. Here, each local virtual domain is closely correlated with each other, because they are located at the outer side of th eoverall triangular spatial form shaped by the three building clustes. Each perimeter virtual spatial domain at the outer border of the triangular form is more closely associated with the exterior landscape than with each other.

Within each cell space, the overlay of the jprimary columns and walls onto the secondary structure, partition walls or a glass enclosure also generate local virtual spatial forms. At the spaces where the primary structure guides the position of the secondary structure, such as the cell spaces at the south and east clusters, the orthogonal form dominates the physical spatial definition. A greater elaboration on the non-orthogonal geometries can be formed where the secondary enclosure guides the position of the jprimary structure, which is seen at the north cluster. As a result, the cell spaces at the north cluster suggest more local virtual spatial domain than we find at the south cluster.

The virtual spatial form thus generated by layers of structure-verus-spatial form at Lorch High School occurs in large scale, found in the central lobby, as well as in small scale, found in the subdivided cell spaces, and in the interior as well as at the exterior perimeter. The diversity and locality of virtual space in this building context are the predominant spatial feature that is ecoed through the diversified structural forms of each cluster.

Chapter 6

CONCLUSION

The Three Cases, A Comparision

Spatial and structural form in Greco-Roman masonry and Chinese timber-frame buildings tend to complement each other with respect to spatial geometry. Such a complementary relationship centers around the orthogonal form, whether virtual, literal, or physical. I term these standard, orthogonal organizations the "conventional types" of the two cultures. In an evolutionary process, structural form may move beyond these conventional types, resulting in modified spatial forms. Some examples are the transformation from one to two rows of columns, or a change from a Romanesque to a Gothic structure. Alternatively, the spatial form may undergo a transformation from a simple geometric configuration to a complex one, which then leads to a transformation of the structural form. Variations of spatial typology in Palladio's designs demonstrate this type of shift.

Despite these evolutionary changes, we must begin by recognizing that also in conventional buildings the construction and configuration of columns and walls show varied spatial phenomena. The columns may suggest virtual space beyond the literally defined spatial form, while the walls provide a range of space from the virtual to the physically confined. In these conventional buildings, columns as structural forms thus override their role as spatial forms, while walls as spatial forms override their role as structural forms. Walls may eventually escape their bearing duty and become purely non-bearing partition walls. The interplay between columns and walls, and between bearing and non-bearing functions generates a complex structure-versus-space relationship.

In light of the complementary correlation which exists between structural and spatial form in the conventional model, this study has examined how three cases, employing modern building materials and structures, demonstrate a wide range of structure-versus-spatial relationships.

At Lorch High School the non-orthogonal spatial form extends beyond the conventional model and influences most of the structural decisions. Here, the structural form, as a response to the spatial form, presents an innovative device in which the primary structure, made up of either columns or walls, generates mostly virtual spatial form which relies on the physical enclosure of the glass facade to complete the spatial definition. This physical enclosure either corresponds to the virtual form of columns and walls or is an overlay of different geometric form. In other words, the physical enclosure may or may not relate to the geometric form of the primary structure. In Behnisch's design process, the physical enclosure, in most cases, actually influences the positions of the primary structures. The use of a non-bearing enclosure as the major spatial form, which at the same time guides the layout of the primary structure, is a reverse of the conventional structure-versus-space relationship.

The Carpenter Center is a case where the physical spatial form, mostly shaped by a non-bearing enclosure, also dominates the structural scheme. However, the use of an orthogonal modular grid as the predominant structural form for the concrete columns displays a sympathy towards the conventional complementary structural and spatial relationship.

Columns, as the primary structure of the Carpenter Center, suggest a virtual form, which does not literally correspond to the physical enclosure. At some locations, the virtual form of the column scheme is independent from the physical spatial form. This is especially true at the ground floor, where the columns generate a promenade, a radial domain, and other spaces unrelated to the formal geometries of the enclosure. At other locations, the orthogonal virtual form of the columns is echoed by an orthogonal physical enclosure such as at the fourth and fifth floor of the Center.

As dominant physical enclosures, the concrete walls by themselves suggest both literal enclosures and virtual space. These virtual spatial domains are independent from the literal physical enclosure. They form the predominant virtual spatial demarcation within each singular spatial volume. These spatial volumes are formed by a gathering of various virtual spatial forms defined by varied shapes of concrete walls and other infills, such as concrete struts, glass, and other elements.

Finally, in the design of Exeter Library, spatial form and structural form coincide as one coherent building form. Because the virtual spatial form of the library structure corresponds to the physical or literal spatial form, the Exeter Library is the closest of the three cases to the conventional structure-versus-space correlation. The pier-walls at the Library suggest a correlated virtual and physical form, differing from the varied wall sections at the Carpenter Center. In the latter case, the virtual spatial forms are independent from the physical spatial form. Though the Library is formed by varied structural schemes at each of the three structural zones, the virtual geometric connection of these varied forms is greater than the literal spatial form at each individual zone.

The primary structure at Exeter Library, thus, is its dominant building form, while the secondary enclosures at Lorch High School and the Carpenter Center make up their dominant building form.

Columns and Walls, The Tendency Towards Virtual Spatial Forms

In the above three modern cases, we see the tendency toward virtual spatial forms not only in the column scheme, but also in the design of secondary walls. The box-formed bearing walls that enclose and define the conventional buildings give way to planar walls which allow varied openings for light, as is the case at the Carpenter Center, or L-and U-shaped containment walls of smaller scale to serve as interior structural support, as found in the Exeter Library and the north cluster of Lorch High School. In other buildings of Louis Kahn, such as the Richards Laboratories at the University of Pennsylvania, the containment walls are both major interior and exterior structures.

As the exterior enclosure, the planar bearing walls are combined with light-weight materials either to introduce a variation of planar surfaces and shapes such as at the Carpenter Center and the east cluster of the Lorch High School, or to introduce repetitive solid and void intervals, which is the case at the Exeter Library. The variation of planar surface and shape may range from an extensive bearing wall surface combined with small openings to an extensive opening surface combined with narrow planar walls. At the Carpenter Center, the retreat of the solid walls from a bearing to non-bearing structure allows for an irregular proportional and positional play between solid walls and openings. This applies to both planar and containment walls. The irregular positioning of either the planar walls, which project virtual space, or containment walls which confine virtual space, leaves them independent of the singular spatial form that they form as parts. However, the regular positional relationship between solid walls and openings projects virtual spatial forms that are often coherent parts of the physical spatial form they define.

As parts of the interior structure, the bearing walls generate strong internal spatial demarcations, especially when they are exposed in the void, such as the L-shaped interior walls at the north cluster of Lorch High School. Another example of walls as interior structure is found in the containment walls that confine the service spaces in the Exeter Library. In conventional masonry buildings, the interior bearing walls often are attached to the exterior bearing walls, which conceal their tectonic presence at the same time as they enclose space. Such a spatial scheme of interior bearing walls defines only physical spatial forms. When the interior bearing walls are exposed, or partially exposed in the void, they start to generate a virtual spatial domain which shows a strong relationship to the adjacent spatial form, and allows for a varied spatial definition. Similar to the interior columns, the interior bearing walls help to support a large-span roof, facilitate roof openings, or continue the exterior structure into the interior. While different from the interior columns, the interior walls generate stronger spatial demarcations. Beyond a certain length, they separate spaces functioning as the conventional partition walls.

When composing the major structure, the interior columns or walls permit the use of glass or light weight materials in the exterior enclosure, as is the case at Lorch High School and the Carpenter Center. As for the building boundary layout, this exterior enclosure is constrained by the spanning distance and geometry of the interior structure found in the Carpenter Center. At Lorch High School, the semi-self-support glass facade breaks away from such a constraint, and allows a spatial geometry semi-independent from that of the primary structure.

The tendency toward a virtual spatial form in modern materials is also manifested in the column system. In conventional buildings, the column system, or column and wall system, reveal a literal spatial form while suggesting virtual ones. The orthogonal spatial geometry and the regularity of the structural scheme contribute to such a phenomenon. In modern cases, the non-orthogonal scheme and the irregular intercolumination, found in Lorch High, or in the Carpenter Center (where the modular grids form an irregular column scheme), enhance the virtual spatial definition. The varied spatial zones in the whole column scheme define local virtual spatial forms, often unrelated to the literal spatial form as a whole. This phenomenon also applies to columns and walls placed in a non-orthogonal disposition.

In the tendency towards a virtual spatial definition, we see that columns start to play an important spatial role apart from their role as structural supports. Walls, especially non-bearing walls (such as the self-supported glass facade), start to question tectonic possibilities, not only their role as supports but also the formal attributes that contribute to supports.

Figures

fig. 3-1 A. W. Lawrence, Greek Architecture.
fig. 3-2 Ibid.
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fig. 3-4 A. W. Lawrence, Greek Architecture.
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